بسم ا الرحمن الرحيم

ASSESSMENT OF WIND ERODIBILITY OF SOIL USING GIS TECHNIQUES: KASSALA STATE, SUDAN

By

Intisar Elmammoon AbdEl Gadir

B.Sc. (Agriculture Science
Faculty of Agriculture
University of Khartoum

Supervisor
Professor Mukhtar Ahmed Mustafa

A dissertation submitted to the University of Khartoum in partial fulfillment of the requirements for M.Sc. in Desertification

Desertification and Desert Cultivation Studies Institute
University of Khartoum

December, 2007

DEDICATIION

To the soul of my mother
To the soul of my sister
To my father
To myhusband
To my brothers
To my sisters

ACKNOWLEDGEMENTS

I consider myself fortunate to have been awarded the UNESCO Chair of Desertification Studies Scholarship; I would like to express my thanks to the Chair for the support it has given me. Special thanks, appreciation and indebtedness to my supervisor Prof. Mukhtar Ahmed Mustafa for his encouragement and help throughout the course of this study. My gratitude is extended to the staff of the Desertification and Desert Cultivation Studies Institute, U. of K., for academic and assistance. Thanks are also extended to The Ministry of Agriculture, Irrigation and Animal Resources Kassala State, for their help and cooperation during the field sampling. Sincere gratitude is also expressed to my friend Asmahan Hessian and her family for their help. Finally, I am grateful to my father for his encouragement.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

ABSTRACT

Wind erodibility of soils (WE) is a major indicator for prediction, assessment and mapping of wind erosion.This study was undertaken to assess and map non-erodibile particles >0.84 mm and wind erodibility (WE) of soils of Kassala State. Surface (0-3 cm) soil samples were collected from 50 locations, covering most irrigated and rain-fed schemes. Non-erodibie soil particles (NEP) were measured and their equivalent WE were estimated using a standard Table. Pertinent soil physical and chemical properties were measured.Non-erodible particles ranged between 15% and 65.9 % and WE ranged between 36 ton/h and 262 ton/h.Regression analysis showed significant increase in NEP with increase in clay (C) (r^2=0.4245), organic matte (OM) (r^2=0.92) and decrease of sand(S)(r2=.2821). Silt (Si) had no significantly impact on NEP or WE. Furthermore, NEP increase significantly with increase of C/(Si+S) (r^2=0.4218), and decrease (Si+S)/C (r2=.3353), (Si+S) /(C+OM) (r2 = 0.4611) and (Si+S) / (C+$CaCO_3$**)** **(**r2=0.3386). Reverse significant correlations were obtained between WE and the same soil variables in sequence. Multiple regression analysis yielded highly significant correlation between the five basic soil proprieties and NEP (r = 0.9400) or WE (r =0.9174).Wind erodibility groups (WEGs) were established for the soils of Kassala State. These WEGs correlated very well with those of Dakota and Alberta. The NEP data was extrapolated and mapped through out Kassala State using GIS technique.

ملخص الاطروحة

إن التعريية الريحية للتربة (WE) هى المؤشر الرئيسى لتقدير وتخريط التعريية الريحية والتنبؤ بها.اجريت هذه الدراسة لتقدير وتخريط تعريية ترب ولاية كسلا وحبيبات التربة غير القابلة للتعرية (NEP)، أى الحبيبات التى أقطارها أكبر من 0.84 مم. الى ذلك تم جمع عينات تربة (0-3 سم) من 50 موقع غطت معظم المشاريع المروية والمطرية.وتم قياس حبيبات التربة غير قابلة للتعرية وتقدير قيم التعريية الريحية المكافئة لها. كما تم قياس بعض خواص التربة الفيزيائية والكيميائية. تراوحت قيم حبيبات التربة غير القابلة للتعرية بين 15% و65.9%، وتراوحت قيم تعريية التلبة بين 36 طن/هـ و262طن/هـ. دلت تحاليـل الانحـدار الاحصائية على زيادة معنوية فى NEP بزيادة نسبة الطين (ر^2= 0.4245) وزيادة المـادة العضـوية (ر^2= 0.9200) ونقصان نسـبة محتـوى الرمل (ر^2=0.2821). ولم يعط السلت علاقة ارتباط معنوية على NEP . كمازادت قيمة NEP معنوياً بزيادة نسبة الطين/(السلت + ا لرمل) (ر^2= 0.4218)، ونقصان نسبة (الرمل+ السلت)/(الطين + المادة العضوية) (ر^2=0.4611)، ونقصان نسبة (السلت +الرمل)/(الطين +كربونات الكالسيوم) (ر^2=0.3386). ولقد وجدت علاقات ارتباط معنوية عكسية بين تعريية التربة وكل هذه المتغيرات ونسبتها على التوالى. واعطت تحاليل الانحدار متعددة الحدود علاقة ارتباط عالية المعنوية بين خواص التربة الاساسية الخمسة وحبيبات التربة غير القابلة للتعرية (ر^2= 0.9400) أو تعريية التربة (ر^2= 0.9174). كما انشأ جدول لمجموعات تعريية لولاية كسلا. أعطت هذه المجموعات علاقة ارتباط معنوية بينها ومجموعات تربة" داكوتا" (Dakota) "البرتا" (Alberta)

.كما تم اسقاط بيانات حبيبات التربة غير قابلة للتعرية وتخريطها فى الولاية مستخدما تقنيات نظم المعتومات الجغرافية.

CHAPTER ONE
INTRODCTION

Desertification is recognized globally as a complex disaster having interactive biological, ecological and socio-economic impacts in the dry lands of the world. It is defined as "land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors including climatic variations and human activities" (UNCCD, 1994). Two main factors are indicated in this definition, namely; climatic variations and human activities. The former factor consists of recurrent drought cycles and fluctuation of annual rainfall patterns. The anthropogenic factor consists of improper agriculture practices, mechanized rain-fed agriculture, shifting cultivation, misuse of land cover (over grazing and deforestation by fire and tree cutting to satisfy urban demand for Charcoal), and misuse of agricultural inputs (fertilizers and Pesticides).

The consequences of desertification are decrease of agricultural land; range and forest land, depletion of soil fertility, decline in biodiversity, environment pollution, reduction of land resistance to natural climatic variation and vegetation damage. Furthermore desertification contributes to famine and has enormous social costs.

The Sudan is the largest arid country in Africa; thirty one percent of the country is hyper-arid, and about 63% are dry lands that are susceptible to desertification (Ayoub, 1998). Wind erosion is great in arid and semi-arid areas where the following conditions occur; loose dry and finely divided soil, smooth soil surface devoid of vegetation cover, large fields and strong winds (FAO, 1960). Wind erosion is affected by soil erodibility, wind erovisivity, nature and degree of plant cover. Soil erodibility is the susceptibility or ease of detachment and transport by wind. It is a primary variable that affects wind erosion. The resistance of soil to the wind erosion depends on the average wind force, roughness of soil surface, moisture content of the soil, soil texture, particle size distribution, soil organic matter content, shear strength, and type and density of the vegetation cover.

Chepil (1950) determined relative erodibility of soil reasonably free from organic residues as a function of apparent specific gravity and proportions of dry soil aggregates in various sizes. Clods larger than 0.84 mm determined by dry sieving, are considered non- erodibile fractions (Chepil and Woodruff, 1954).

Wind erosion is the predominant desertification process in Sudan. Very limited research was conducted on the assessment and mapping of wind erosion. A research project on wind erodibility was initiated by the Desertification and Desert Cultivation Studies Institute. Wind erodibility of soils from several states was measured and correlated with several basic soil properties. The research which was conducted previously did not include Kassala state. Thus the main objective of the present research is to assess and map soil erodibility of some agricultural soils of Kassala State. The specific objectives are: (i) estimation of soil erodibility of studied samples, (ii) identification of soil properties that can be used as indicators of wind erodibility, (iii) establishment of wind erodibility groups, (iv) correlation of these groups with global groups, (v) mapping of wind erodibility of the soil of Kassala State by using GIS technology, (vi) comparing the results of this study with those of local previous studies for other states.

CHAPTER TWO
LITREATURE REVIEW

2.1 Desertification Processes:

Desertification is an environmental socio-economic problem that occurs in the dry lands of the world. In the United Nation Conference on Environment and Development Convened at Rio de Janeiro, Brazil (1992), desertification was defined as: “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities”. Land degradation results from one or more processes which reduce the current and potential capacity of land to produce quantitively, qualitatively goods and services (FAO, 1977). Four main desertification processes were identified, namely vegetation degradation, wind erosion, water erosion and salinization/ sodication. There are other four secondary processes, namely loss of organic matter, crusting/compaction, accumulation of substances toxic to plants and animals and water logging.

2.2 Wind erosion:

Wind erosion is a serious problem in many parts of the world. It occurs in arid and semi-arid regions. Soils of humid climate that experience occasional drying are also vulnerable to wind erosion. Wind erosion is defined as: "the soil physical process by which dry loose and fine surface soil particles are picked up and transported or moved on the ground surface by wind and the soil surface material is abraded by wind born particles (Mustafa, 2007). The erosive wind removes organic matter, fine silt and clay fraction, and leaves gravel and sand. This process makes the surface soil coarse in texture and more eroded and less productive than it originally was (Stalling, 1955). The way in which the detached soil particles are transported by wind depends on their size. Most of the grains move by saltation such as sand particles of sizes ranged from 0.1 to 0.5 mm in diameter, and the smallest particles detached during erosion like silts and clays are carried in suspension by wind to great heights, and the larger grains, (up to about 1 mm in size) move by rolling a long the soil surface by a process known as soil creep. In general, wind erosion is the predominant desertification process in Sudan, it affected 27 million hectare most of which in the hyper-arid zone of Sudan, where vegetation cover is poor and soil particles are loose and accelerated by strong winds characteristic of region (Ayoub, 1998). However, wind erosion is predominant in almost all States in the northern part of Sudan.

2.2.1 Causes of wind erosion:

Wind erosion is caused by combination of adverse climatic variation, climatic change and adverse human activity.

(a) Adverse Climatic Variation:

Climatic variation is a feature of arid and semi -arid zones where severe recurrent drought spells occurs. These conditions coupled with poor sandy soils, fluctuation of rainfall and misuse of land lead to land degradation by accelerated wind erosion. High aridity is an adverse climatic condition that creates fragile ecosystem, which can easily be upset by adverse anthropogenic activities. These conditions also lead to land degradation by accelerating wind erosion.

(b) **Climatic Change:**

Climatic change may induce geographical changes in ecological zones. The climate controls the land use system; land use system may induce change in the weather and the climate. Sagan *et al*. (1979) suggested that anthropogenic environment change including accelerated wind erosion have been responsible for climate change during the past several millenniums. Tool and Pollack (1990) concluded that soil, soot, and sulfates arising from human activity probably are warming some regions of the earth while cooling others.

(c) Human activities:

This constituted the main factor in rural areas of the arid and semi -arid land where the poor people seek sustenance from the natural resource of their fragile ecosystem. They cultivate their marginal land to secure stable food, overcut forests to establish their homes and animal enclosures and their animal over graze the land. Generally, overgrazing of livestock affects 30 million hectare mostly in arid zone causing wide spread wind erosion (Ayoub, 1998). Other human activities that contribute to accelerated wind erosion are cropping without use of appropriate nutrient inputs and lowering of water tables due to excessive usage of water at water points.

2.2.2 Mechanism of wind erosion:

The process of wind erosion consists of two steps, namely detachment of soil particles from the soil mass and their transport by erosive wind. There are three mechanisms of particle movement, namely suspension, saltation, and surface creep.

(a) Suspension:

Very fine soil particles less than 0.1 mm in diameter enter into suspension and be carried to great heights by erosive wind. The movement of these fine particles may be initiated by the impact of saltating particles.

(b) Saltation:

Saltation is the movement of soil particle in a series of short jumps. The wind pressure causes the soil particle to bounce off the soil surface into the air stream and move forward before returning to the surface with an angle of descent of about 6 - 12° from the horizontal (Chepil and Woodruff, 1963). Most saltating particles range between 0.1 and 0.5 mm in diameter. Almost so to 75% of the movement is by salutation.

(c) Surface creep:

Soil particles large than about 0.5 mm in diameters but smaller than 1.00 mm are to heavy to be moved in saltation and are pushed or rolled along the soil surface by impact of saltating particles this process is called surface creep.

2.2.3 Factors affecting wind erosion:

The rate of wind erosion depends on three main factors, namely, soil erodibility, wind erosivity and plant cover.

(a) Soil erodibility:

Soil erodibility is defined as the susceptibility or ease of detachment and Transport by wind. Wood ruff and Siddoway (1965) defined soil erodibility as "the potential average annual soil loss from a wide, unsheltered isolated extended field with bare, smooth, non-crusted surface." Soil erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity, soil organic matter and chemical constituents. The important soil factors that affect soil erodibility are plant cover, topographic position, slope steepness, soil properties. However, the soil particles are the most important determinants of soil erodibility (Morgan, 1995). Some soil factors are presented in this section.

(i) Particle-Size distribution:

Particle –size distribution is an important soil property that affects soil erodibility because it affects both detachment and transport processes. Generally, large particle are resistant to transport because of the greater wind force required to entrain them, and that fine particles are resistant to detachment because of their cohesiveness. The least particles resistant to detachment are silt and fine sand, thus soil with high silt content is highly erodible. Richter and Negendank (1977) showed that soil with 40-60% silt content were the most erodible. Evans (1980) noted that soil with restricted clay fraction between 9 - 30 percent were the most susceptible to erosion. Wood ruff and Siddoway (1965) noted that soil particles larger than 0.84 mm in diameter were considered non-erodibile and their percentage was used for estimating wind erodibility of soils. Generally, resistance to wind increases rapidly when primary particles larger than 1 mm in diameter are predominant. (Morgan, 1995).

(ii) Aggregate stability:

Generally, aggregated soils are less erodible than dispersed soils. Therefore, all agents that promote aggregatation will inhibit soil erodibility, such as polysaccharide, which is a derivate of organic matter. Furthermore, divalent cations such as calcium (Ca^{++}) promote flocculation and hence reduce erodibility and on the contrary the sodium ions (Na^{+}) cause dispersion and enhance erodibility. Thus, soils with low electrolyte concentration and high sodium adsorption ratio are more erodibile than soils with high electrolyte concentration and low sodium adsorption ratio i.e. sodic soils are more erodibile than saline, and saline-sodic soils (Hamid and Mustafa, 1975). Calcium carbonate ($CaCO_3$) may act a cementing agent and enhance the formation of clods. Black and Chansyk (1989) found that increasing quantities of soil carbonate, up to 10% decreases soil erodibility. Borohono *et al.* (1990) found that excess calcium carbonate with high clays/silts fractions leads to high erodibility. High of exchangeable sodium percentage deteriorates soil structure on wetting, with consequent loss of soil strength, followed by the formation of a surface crust and decline in infiltration as the detached clay particles fill pore spaces in the soil (Shainberg and Letey, 1984). Also aggregate stability depends on the types of clay mineral present. Illite and smectite more readily form aggregates but the more open lattice structure of these minerals and the great swelling and drying render the aggregate less stable than these formed from koalinite (Morgan, 1995).

(iii) Organic matter:

Organic matter promotes aggregate stability, increases water holding capacity, and in sandy soils improve soil texture, thus organic matter reduces soil erodibility. Evans (1980) noted that soils with less than 3.5% organic matter content can be considered erodibile soil. Voroney *et al.* (1981) suggested that soil erodibility decrease linearly with increasing organic matter content in the range of 0.0 to 12%. The effect of organic matter on aggregate stability depends on its origin whilst organic material from grass, leys and farm yard manure contribute to stability of soil aggregate Peat and undecomposted haulm merely protect the soil by acting like a mulch and do little to increase aggregate strength (Ekwue *et al.*, 1993).

(iv) Shear strength:

The shear of a soil is a measure of its cohesiveness and resistance to shearing forces exerted by gravity, moving fluids and mechanical loads soil strength is derived from the frictional resistance met by its constituent particles when they are forced to slide over one another or to move out of interlocking positions, the extent to which stresses or forces are absorbed by solid to-solid contact among the particles ,cohesive force related to chemical bonding of the clay minerals, and surface tension forces within the moisture films in un saturated soils (Morgan, 1995).

(v) Moisture content:

Generally, wet soils are not susceptible to wind erosion. The resistance of soil to wind erosion depends upon dry than wet aggregate stability and on moisture content. As the soil moisture content from air-dry level increases, wind erosion decreases until it stops completely when the soil becomes wet.

(b) Wind erosivity:

Wind erosivity is the indicator of wind energy that cause wind erosion. There are two indicators of wind erosivity, namely, the pressure of wind acting on surface perpendicular to the direction of wind, and Skidmore and Woodruff index (1968) which is based on the velocity and direction of wind. The latter wind erosivity index is calculated by the following formula

$$Wr = \sum_{j=0}^{j=15} \sum_{i=1}^{i=n} V^{3}ij\ fij$$

Where:-

Vij = Mean wind velocity above a given threshold velocity (5.4 m/sec) within the ith velocity group for the ith direction.

fij = The duration of wind within the ith velocity group for the ith direction expressed as a fraction of the total duration.

$\sum_{j=0}^{j=15}$ = The summation of the Wr index for directions from j=0 at the east **d**irection and working anticlockwise so that j =1 at ENE and j = 15 at ESE,

$\sum_{i=1}^{i=n}$ = The summation of the Wr index for velocity groups from the first group i = 1 to the n group j.

There are five of soil surface rough nesses elements that influence wind speed and hence wind erosivity, these elements include:

(i) Vegetation:

Vegetation height and density are the most important properties of vegetation that affect surface roughness, since these determine the extent to which air flow contacts the ground surface and influences of the height of mean aerodynamics surface. Their values vary with vegetation type and season and for annual crops they depend on crop species, variety and stage of crop development. Chepil and Woodruff (1963) noted that grasses and legumes are most efficient in establishing a dense plant cover.

ii) Clods and non-erodibile fraction:

Erosion of a land surface continues until a sufficient number of non-erodible fractions are uncovered at the surface. At this stage, the non-erodible fractions provide direct cover and shelter for the remaining erodible particles on the surface. This condition may alter with a change in the wind direction. The point at which this cover is just sufficient to prevent movement from continuing or starting is called the critical surface barrier ratio. Originally it was called the critical surface roughness constant (Chepil, 1950).

(iii) Ridges:

Ridges reduce wind erosion by sheltering and trapping when the wind blows at right angles to them. This effect is reduced when the winds blow parallel to them. Chepil and Milne (1941) investigated the influence of surface roughness on intensity of drifting dune materials and cultivated soil, they found that the initial intensity of drifting was always much less over ridged surface. Ridged cultivated soil reduces the severity of drifting, but high ridges construction from erodibile dune material was less effective because they disappear rapidly.

(iv) Field Shelter belts:

Shelter belts are essential for preventing wind erosion; they provide protection against wind erosion especially in the dry regions where the plant cover is poor. Furthermore, shelter belts have beneficial effects on crop yield through reducing wind velocity, increasing humidity and suppressing evaporation from open surfaces. Effects on temperature can be positive or negative depending on the configuration and orientation of the belts (Hussein, 2007). Shelter belts are a row or multiple rows of trees and/or a hedge placed at right angle to wind. Chepil and Woodruff (1963) noted that the maximum amount of protection is provided by a barrier whose cross-section is either triangular or sloping to the windward rather than vertical to the windward; and that little additional protection is gained by increasing the barrier width beyond five rows.

(v) Local changes in topography:

Soil loss increases rapidly with both increase of slope and distance towards the top of the knoll for windward slope less than about 150 m in length.

(c) Effect of plant cover:

Vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above ground components such as leaves and stem, absorb some of energy of wind, so that less is directed to soil, whilst the below ground components comprising the root system, contribute to mechanical strength of soil. Plant cover varies in effectiveness to reduce erosion depending on the type of plant cover. Forests are the most effective, but a dense growth of grasses may be almost as efficient and quicker to prevent wind erosion. Annual grown field crops vary in their effectiveness depending on their stage of growth and the amount of bare ground exposed to erosion. For adequate protection at least 70% of the ground surface must be covered (Elwell and Skocking, 1976), but reasonable protection can be achieved with 40% cover.

2.2.4 Impact of wind erosion:

Wind erosion has on-site, off-site, national and global impacts. Regardless of where the damage occurs, far-reaching consequences of soil erosion result in significant social, economic and environmental costs.

(a) On-site losses:

The soil surface horizon, which is rich in organic matter and nutrient, is exposed to erosive forces of wind; soil loss by erosion reduces soil quality because erosion removes vast amounts of valuable components of organic matter and fine mineral particles. These effects reduce cation exchange water holding capacity, and also decrease biological activity, in case of severe erosion, the entire surface horizon may be removed these by exposing the underlying B and C horizon.

(b) Off-site losses:

Dust obscures visibility and pollutes the air causing automobile accidents, foul machinery and imperils animal and human health, lowering the marketability of vegetable crops, increasing the suscepti-bility of plant to certain types of stress including diseases, and contributes to transmission of some plant Pathogens (Clafin *et al*., 1973; Hayes, 1965, 1966). Skidmore (1979) stated that the blowing soil reduces survival and growth of the plant.

(c) National impacts:

In addition to on-site losses and off-site losses wind erosion has national and global impacts. The reduction of crop yields in different States may create a food gap and create food insecurity. Desertification in general, may reduce the national biodiversity. Many crops (wheat, barley, sorghum, millet) and several odder species originate from arid and semi-arid zones that are vulnerable to desertification which will reduce this natural irreplaceable bank of native plants Loss of the population of these plants and their wild species is loss of irreplaceable genetic materials. The suspended soil particles affect the scattering absorption of solar radiation and hence affect the microclimate (Mustafa, 2007).

2.2.5 Control of wind erosion:

Wind erosion is easier to prevent than to stop. Wind erosion can be controlled most effectively by increasing soil moisture, reducing soil surface wind velocity, and improving the surface characteristics. Increasing soil moisture leads to increasing soil particles cohesiveness, and, therefore increases the wind velocity required to detach individual grain so that wind erosion is reduced. Level of wind velocity can be reduced by maintain a well anchored crop residue such as stubble mulch from previous crop, or/and by tillage practices, which increase surface roughness, and planting wind breaks. Here are three basic methods to control wind erosion:

(a) Establish and maintain vegetation and organic residues:

The best method to prevent wind erosion is to keep continuous vegetation cover more than 50% all year round living vegetation or residue from harvested crops protect the soil against wind erosion. Standing crop residues provide non erodibile elements that absorb much shear stress in the boundary layer. When vegetation and crop residues are sufficiently height and dense to prevent intervening soil surface drag from exceeding threshold drag, soil will not erode.

(b) Rough, cloddy surface:

Tillage operations that leave furrows or ridges reduce wind erosion. When ridges are nearly gone, vegetation cover is depleted, and the threat of wind erosion continues, a rough, cloddy surface resistant to the force of wind can be created on many soils with appropriate emergency tillage. Emergency tillage is most effective when done at right angles to the Prevailing wind direction because clods eventually disintegrate (Woodruff *et al.*, 1972; Woodruff *et al.*, 1957).

(c) Field shelter belts and wind breaks:

Shelter belts and wind breaks are essentials to prevent soil blowing and wind erosion; they provide protection against wind erosion especially in arid and semi-arid areas where the plant cover is rare. Shelter belts have many benefits, these benefits include improve soil organic matter, recycling plant nutrients; improve rainfall infiltration, catchment protection, provision of wild life habitats.

2.3 Geographic information system (GIS):

The GIS is a computer based tools for mapping and analysis of things that exist and events that happen on earth. ESRI (i995) defined GIS as: "an organized collection of compute hardware, software, geographic data, and personal, designed to efficiently capture, store, update, manipulate, analyze and display, all forms of geographically referenced information. GIS Provides a powerful tool to create maps, integrate information visualize scenarios, solve complicated problems and develop effective solutions. GIS technology integrates common data base operations such as query and statistical analysis with the unique visualization and geographic analysis benefit offered by maps. These abilities distinguish GIS from other information systems and make it valuable for explaining events, predicting outcomes, and plan strategies.

2.3.1 GIS application in desertification:

Geographic information system and global poisoning system induce important techniques, which showily be exploited in desertification studies. Hassan (2006) studied wind erodibility of the Nile state soils with the use of GIS technology. He noted that most of the Nile state is highly erodibile this may be attributed to the geographic location of the State in dry zone where low or absent rains, scares vegetation and dry soils surface prevail.

Rinos *et al*. (2007) used GIS and remote sensing to assess soil erosion at Bata River Basin, in India. They generated a composite map of erosion intensity based on the advanced GIS. Functionality this intensity map, was classified in to different priority classes, study area further more sub water sheeds to identify the priority areas in terms of erosion intensity.

Harahsheh and tateishi (2007) were applied satellite remote sensing and GIS technology as essential tools to address important aspects of environmental monitory and suggested that based on environmental GIS data base a desertification studies will be achieved these studies will include drought assessment; a desertification modeling and the construction of desertification monitoring system.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Physical and environmental setting of the study area:

The study area was conducted in Kassala State, which is affected by desertification.

3.1.1 Location and boundaries:

Kassala State lies between latitude 14.15 and 17.15°N and longitudes 34.30 and 37°E. It is bounded by Ethiopia in the east, Khartoum State in west, the Red Sea State in the north, and in the South by Gredarif State.

3.1.2 Physical features:

Climate:

The climate in the State varies from arid to semi-arid. The rainfall ranges From 300 – 400 mm. The mean temperature is very high in May it is about 33.8°C. Relative humidity is about 43%, the vapor pressures is about 952.3 mb. Short wave radiation is 8.2 calories cm^{-2}. Winds may blow from NEN, SW, and S with mean speeds of 8 M.P.h causing considerable soil erosion (Kassala Station).

Hydrology and geology:

According to the geological map of Sudan of 1981, the State is underlain by Basement complex, which is covered by clay plain and the alluvial sediment that was deposited by the Gash River and eastern Khors and wadis.

Soil and geomorphology:

The soils of the State are divided into the following eight physiographic regions on the basis of gemmorphogy and properties of soil:

1) Desert pediplain.
2) Red Sea Hills.
3) Pediment, gravelly surface.
4) Flat aggradational south central clay plain.
5) Kerrib region.
6) Wadies Alluvium
7) Gash delta.
8) Flat aggradational North central clay plain.

3.1.3 Vegetation covers:

There is a wide variation in vegetation types related to soil types and relief. The dominant native trees are *Tamarix* spp (Tarfa), *Acacia nilotica* (Sunt), *Acacia seyal* (Talh), *Ziziphus spinachristi* (Sidr), *Acacia ehrenbergiana* (Sallam.) and Muskeet *Prosopis spp*. The dominant native shrubs are *Capparis decidua* (tundub) and *Calatropis procera* (usher). Weeds are numerous such as Indigo *Era oblongifolia*. The mean crops are cotton, sorghum, groundnut, Wheat and folder corps is grown in new Halafa scheme. Fruit trees are grown (mango, guava, banana and vegetable like onions.

3.1.4 Source of water:

There are two main sources of water, namely surface water and ground water.

3.1.5 Land use system:

The various land use systems adopted in Kassala State include the following systems:

1) Agriculture practices include irrigated agriculture (flush irrigation in Gash scheme, gravity irrigation in new Halfa scheme), and terrace cultivation.
2) Grazing practices (camels, sheep, goats, and cattle).
3) Wood collection for building and fuel materials.
4) Fishing and wildlife.
5) And urban lands (Younis and Abdalla, 1987).

3.1.6 Population:

According to census of 1983, Kassala State has population of 1512270 with a density of 12 person per kilometer.

3.2 Materials:

3.2.1 Global positioning system (GPS):

It is an instrument that single from satellites and permits land, sea, and air borne user to determine their dimeational position, velocity and time. European space Agency (ESA, 1998) defined GPS as it is satellite based navigation system developed and operated by United States Department of Defense. The position of the studied samples was determined by Gamin's GPSMAP 60CSx which is a type of GPS receiver.

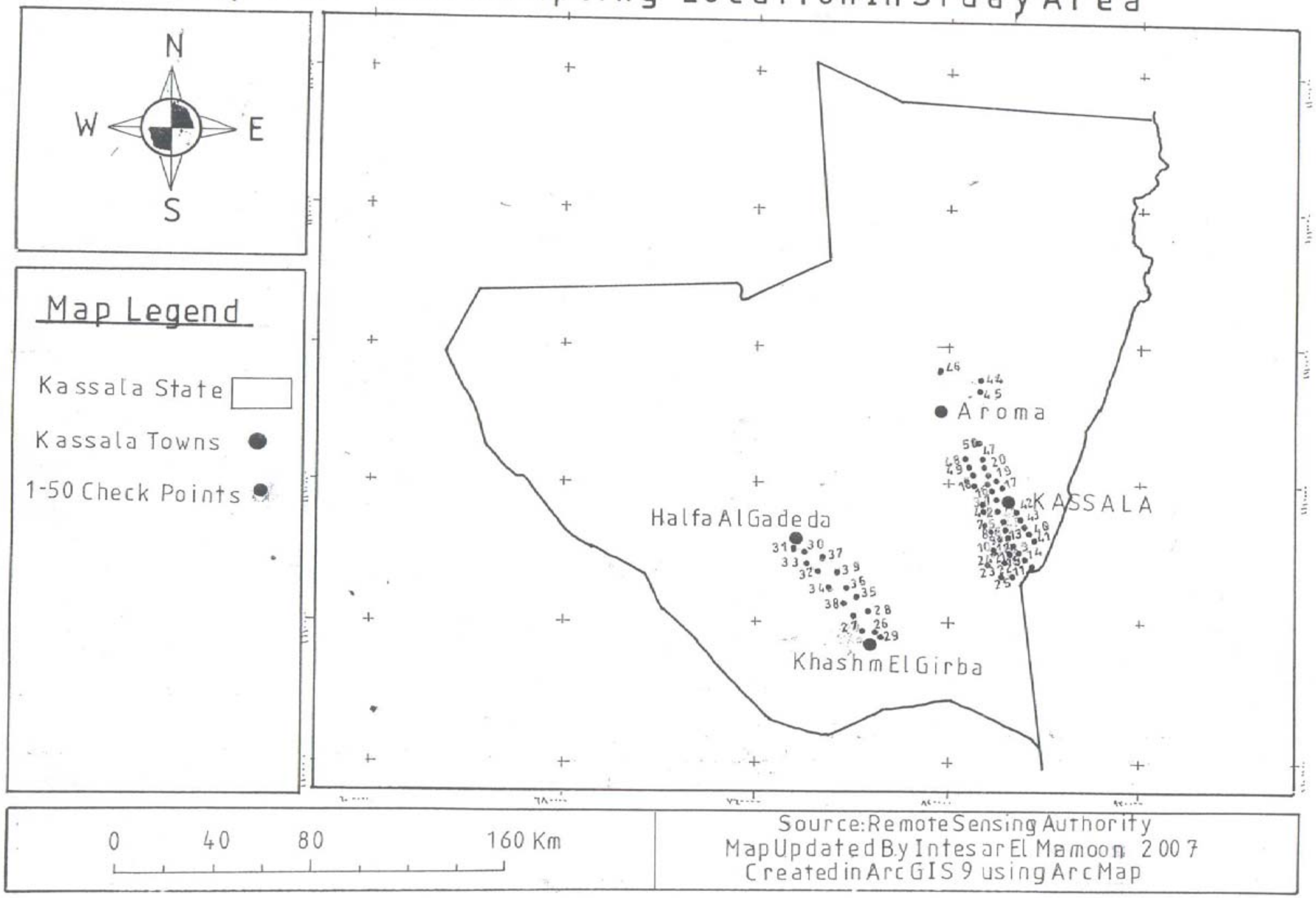
3.2.2 Soil samples:

Surface soil sample differing in texture were collected from 50 farms after completion of land preparation operation for season 2006/2007 (Table 3.1, MAP 3.1). Three surface soil samples from (0 - 3 cm) depth per farm were taken, carefully from a transect a cross the agricultural field using a spade, 1 to 1.5 Kg was taken for each sample to estimate the percentage of particles large than 0.84 mm in diameter (NEP), then the samples were saved in bags for laboratory analysis's.

Table 3.1: Names and location of studied soil samples

NO.	name	X	Y
1	Elsawaggi Elgnobia 1	15.4197	30.3881
2	Elsawaggi Elgnobia 2	15.4378	30.3866
3	Elsawaggi Elgnobia 3	15.4386	30.4092
4	Elsawaggi Elgnobia 4	15.4219	30.3931
5	Elsawaggi Elgnobia 5	15.4145	30.3946
6	Tagog Elaliab	15.3424	30.4133
7	Tagog Senkat Kenab	15.3065	28.5531
8	Tagog Wd shrfie	15.3333	30.3985
9	Tagog Norma	15.3271	30.3931
10	Tagog Wd shrifei	15.3327	30.3882
11	Tagog Ellfa	15.3317	30.3898
12	Elsabeel	15.3720	30.4021
13	Klahowt 1	15.4705	30.2716
14	Klahowt 2	15.4631	30.2717
15	Klahowt 3	15.4336	30.3277
16	Elswagia elshemlia 1	15.4558	30.3705
17	Elswagia elshemlia 2	15.4650	30.3725
18	Elkromta	15.4727	30.3248
19	Elmshareea 1	15.4841	30.3448
20	Elmshareea 2	15.4858	30.3303
21	Awetla 1	15.4193	30.4112
22	Awetla 2	15.4206	30.4043
23	Awetla 3	15.4158	30.4069
24	Awetla 4	15.4210	30.4001
25	Awetla 5	15.4237	30.4012
26	Elgriba 1	14.9853	35.8746
27	Elgriba 2	14.9722	35.8539
28	Ekther elbzowr	14.9784	35.8810
29	Elgriba 3	14.9896	35.8690
30	Elgria 13	15.2994	35.6270
31	Elgria 12	14.6325	35.6267
32	Elgria13 grab	15.2746	35.6370
33	Elgria 9	15.2574	35.6493
34	Argeen sheemal	15.2264	35.6754
35	Elhsaia	15.2071	35.6907
36	Elgria 3	15.1787	35.7151
37	Elgria 32	15.1378	35.7463
38	Elgria 1	15.1214	35.7633
39	Hancock	15.3870	30.4272
40	Abo lega 1	15.3831	30.4263
41	Abo lega 2	15.3779	30.4306
42	Wd shrfie elrdeef 1	15.3378	30.4437
43	Wd shrfie elrdeef 2	15.1448	28.5833
44	Tendli masga 9 1	15.3749	30.1964
45	Tendli masga 2	15.9490	30.1889
46	Matateeb masga 16	16.0768	30.1512
47	Sawagi khor elshaeegia 1	15.4901	30.3862
48	Sawagi khor elshaeegia 2	15.5023	30.3851
49	Sawagi khor elshaeegia3	15.5038	30.3861
50	Sawagi khor elshaeegia4	15.9032	30.3820

Map 3-1 : Soil Sampling Location In Study Area



3.3 Methods:

3**.3.1 Wind erodibility estimation:**

The percentage of non-erodible soil particles (NEP>0.84 mm) is used for determining soil erodibility by wind. The NEP % was determined by using the dry sieving technique as proposed by Woodruff and Siddoway (1965). Soil samples were air-dried, cleaned from straw and sieved though a 0.84 mm sieve, the soil particles >0.84 were then weight and expressed as percentage of the each soil sample. Table 3.2 was then used to obtain equivalent erodibility.

3.3.2 Chemical and physical analysis:

After the determination of NEP, The two portions of the soil samples were then mixed, crushed, passed through 2 mm sieve and saved for chemical and physical analysis. Parties-size distribution was determined using the hydrometer method described by Black *et al*. (1965). The texture classes of studied samples were determined according to USDA textural triangle. A calcium carbonate content was determined by the acid neutralization method as described by Richards *et al*. (1965). Calcium (Ca^{++}) and Magnesium ($Mg^{++)}$ were determined by titration against EDTA according to method described by Cheng and Bary (1951). Soil pH was determined by using pH –meter, and ECe by ECe-meter. Organic carbon (O.C) and organic matter (OM) were determined according to method described by Walkey (1935). Sodium ($Na^{+)}$ was

Table 3.2: Soil erodibility (ton/ha) as a function of percentage of non-erodibile soils particles (> 0.84 mm) (NEP) as determined by standard dry sieving.

NEP (%)	Soil erodibility (ton/ha)									
	0	1	2	3	4	5	6	7	8	9
0	-	695	560	493	437	404	381	359	336	314
10	300	294	287	280	271	262	253	244	238	228
20	220	213	206	202	197	193	186	182	177	170
30	166	161	159	155	150	146	141	139	134	130
40	126	121	117	114	112	108	105	101	96	92
50	85	80	75	70	65	61	58	54	52	49
60	47	45	43	40	38	36	36	34	31	29
70	27	25	22	18	16	13	9	9	7	7
80	4	-	-	-	-	-	-	-	-	-

Source: Woodruff and Siddoway (1965).

determined by using flame photometer, and sodium adsorption (SAR) was calculated using the equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Where cation concentration are given in meq/L (mmole $^{+}$/L)

3.3.3 Wind edibility groups (WEGs):

Studied samples were grouped into wind erodibility groups according to their textural classes, the mean percentage of (NEP) as calculated for each WEG and compared with those estimation from the WEGs obtained for North Dakota. USA (Chepil, 1962; Chepil *et al*., 1962; Hayes, 1965) and Alberter (Black and Chansyk, 1989).

Statistical analysis and all computation were done by Microsoft Excel 2003 program.

3.3.4 Arc view GIS program:

It is a full-feature soft-ware for visualizing, mapping, creating, analyzing geographic data. Using Arc view the geographic context of data can be understood easily, hence, it allows seeing relationships and identifying patterns in new Ways (ESRI). This program was to design maps to illustrate the distribution of wind erodibility, non-erodibile particles on Kassala State. These maps were design following these steps:

(a) Data input:

- Initially all data was inserted in Excel software and saved as a DBF4 file format.
- Arc View was opened and the table of data was added,

- From new view the option of add event theme was selected to show the location of samples,
- The study area boundary added with all features,

(b) Data management

The location points theme was converted to shape File as well as the state boundary.

- All features data like location point, state boundary converted to a shape format. This process prepared the data for the analysis and organized the data input.

(c) Data analysis:-

For production of spatial maps, interpolation technique used by applying IDW method, which was selected from interpolate surface menu, then Z value field for each map was selected.

- Every map was re-classified from the legend editor window.
- Digitization of each class boundary was made when start editing option was selected from theme options attributes and Id of ever digitized class were modifie from theme table window.
- From legend editor window legend type was selected as unique value, and value of determined as I D, besides the label of class.

CHAPTER FOUR
RESULTS

4.1 Soil properties:

Particles-Size distribution and texture classes of the studied samples are presented in Table 4.1. The mean clay content (C) of individual soil samples ranged from 2 to 33%. The standard deviation SD and coefficient of variation CV of the individual soil samples ranged from 0.0 to 7.1% and from 0.0 to 64.3%, receptively. The overall mean SD and CV for all samples were 1.6 and 11%, respectively. The mean silt content (Si) of the individual soil samples ranged from 1 to 50%. The SD and CV for the individual soil samples ranged from 0.0 to 7.1% and from 0.0 to 141.4%, respectively. The overall mean SD and CV for samples were 1.9 and 13.1%, respectively. The mean sand content (S) of the individual samples ranged from 37 to 97%. Values of SD and CV for the soil individual soil samples ranged from 0.0 to 8.5% and from 0.0 to 11.9%, respectively. The overall mean SD and CV for all samples were 1.5 and 2.6%, respectively.

Nineteen samples were sandy loam, twenty were sandy clay loam, three were loamy sand, three were loam, one was silt loam, one was sand, and one was sandy clay, one was clay loam and one was silt. Most of the studied samples belonged to sandy clay loam texture classes.

Table 4.2 presents the mean values of saturation percentage (SP), pH of the saturated paste, ECe and SAR of the studied samples. The ECe values ranged from 0.1 to 1.8 dS/m. The SD and CV values for the individual soil samples from 0.01 to 0.64 and from 0.0 to 107.5%,

Table 4.1: Mean clay, silt, and sand percentage and soil texture of classes the studied samples.

No.	Clay %	SD	CV	Silt %	SD	CV	Sand %	SD	CV	Texture
1	11	4.20	38.2	17	4.2	24.9	72	8.5	11.87	Sandy Loam
2	11	7.10	64.3	27	1.4	5.3	62	5.7	9.1	Sandy Loam
3	14	0.00	0.0	36	5.7	15.71	50	5.7	11.3	Loam
4	18	5.76	31.4	24	4.2	17.7	58	1.4	2.4	Sandy Loam
5	10	2.81	28.3	30	5.7	18.85	60	2.8	4.71	Sandy Loam
6	16	4.22	26.45	19	1.4	7.4	65	2.8	4.35	Sandy Loam
7	19	0.00	0.0	18	0	0	73	0.0	0	Sandy Loam
8	19	0.00	0.	6	0	0	75	0.0	0	Sandy Loam
9	19	0.00	0.0	5	1.4	28.3	76	1.4	1.9	Sandy Loam
10	19	0.00	0.0	4	0	0	77	0.0	0	Sandy Loam
11	23	0.00	0.0	18	1.4	7.9	59	1.4	2.4	Sandy Clay Loam
12	27	0.00	0.0	20	1.4	7.1	53	1.4	2.7	Sandy Clay Loam
13	20	1.41	7.1	27	0	0	53	1.4	27	Sandy Clay Loam
14	24	1.41	5.9	27	0	0	49	1.4	2.9	Sandy Clay Loam
15	30	1.41	4.7	19	2.8	14.9	51	1.4	2.8	Sandy Clay Loam
16	30	2.81	9.4	17	0	0	53	2.8	3.8	Sandy Clay Loam
17	20	2.81	14.1	19	0	0	61	2.8	4.6	Sandy Clay Loam
18	21	1.41	5.8	24	1.4	5.9	55	0.0	2.57	Sandy Clay Loam
19	20	1.41	7.1	29	0	0	51	1.4	2.77	Sandy Clay
20	8	1.41	17.7	4	1.4	32.4	88	2.8	3.31	Loamy Sand
21	6	1.41	23.6	14	1.4	10.1	80	0.0	0	Loamy Sand
22	21	0.00	0.0	18	1.4	7.9	61.	1.4	2.3	Sandy Clay Loam
23	8	1.41	17.7	4	0	0	88	2.8	3.2	Sandy Loam
24	2	0.00	0.0	1	1.4	141.4	97	1.4	1.5	Sand
25	7	0.00	0.0	15	0	0	78	0.0	0.0	Loamy Sand
26	10	1.41	14.1	32	1.4	4.4	40	0.0	0.0	Sandy Loam
27	16	1.41	8.8	44	4.2	9.6	37	1.4	3.5	Loam
28	33	2.81	8.5	31	2.1	6.8	39	0.0	0.0	Clay Loam
29	11	0.00	0.0	50	1.4	2.8	57	0.0	0.0	Silt Loam
30	24	1.41	3..9	21	1.4	6.7	60	1.4	2.5	Sandy Clay Loam
31	16	1.41	8.8	24	4.2	17.7	51	2.8	4.7	Sandy Loam
32	25	0.00	0.0	24	1.4	5.9	44	1.4	2.8	Sandy Clay Loam
33	19	0.00	0.0	27	0	0	52	0.0	0.0	Sandy Loam
34	18	1.41	7..9	30	1.4	4.7	47	0.0	0.0	Sandy Loam
35	15	2.81	18.9	38	3.5	9.3	61	2.1	4.5	Loam
36	29	0.00	0.0	20	1.4	7.1	51	0.0	0.0	Sandy Loam
37	15	1.41	9.4	32	4.2	13.2	53	2.8	5.3	Sandy Clay Loam
38	20	2.81	14.1	26	7.1	27.2	64	4.2	7.9	Sandy Clay Loam
39	23	1.41	6.1	16	1.4	8.8	71	0.0	0.0	Sandy Clay Loam
40	19	1.41	7.4	12	1.4	11.8	69	0.0	0.0	Sandy Clay Loam
41	26	1.41	5.4	12	4.2	35.3	72	0.0	0.0	Sandy Clay Loam
42	10	1.41	14.1	35	1.4	4	55	0.0	0.0	Sandy Clay Loam
43	23	0.00	0.0	4	1.4	35.3	73	1.4	1.9	Sandy Clay Loam
44	15	2.81	18.9	20	1.4	7	65	1.4	2.2	Sandy Loam
45	15	2.81	18.9	15	2.8	18.9	70	0.0	0.0	Sandy Loam
46	9	2.8	31.4	24	4.2	17.7	67	1.4	2.1	Sandy Loam
47	19	1.4	7.4	20	1.4	7.1	61	1.4	2.3	Sandy Loam
48	8	1.4	17.7	42	0	0	47	1.4	3.0	Silt
49	19	2.8	14.9	18	4.2	23.6	63	14	2.2	Sandy Clay Loam
50	29	0.0	0.0	4	1.4	35.4	67	1.4	2.1	Sandy Clay Loam
Overall mean		1.6	11.0		1.9	13.1		1.5	2.6	

Table 4.2: Mean SP, pH, ECe and SAR percentage of the studied samples.

No.	SP%	pH	ECe ds/m	SD	CV	SAR	SD	CV
1	44.0	8.1	0.31	0.01	0.0	0.03	0.01	500
2	42.5	7.9	0.38	0.03	7.4	0.02	0.01	300
3	49.5	7.7	0.08	0.04	47.1	0.02	0.01	300
4	39.5	7.7	0.20	0.23	11 9.0	0.01	0.00	0.0
5	41.5	7.8	0.11	0.10	6.7	0.01	0.00	0.0
6	41.5	8.4	029	0.04	12.4	0.01	0.00	0.0
7	41.5	2.8	0.10	0.23	7.4	0.01	0.00	0.0
8	41.5	7.5	0.13	0.01	107.5	0.03	0.00	0.0
9	36.5	7.9	0.32	0.04	6.7	0.02	0.01	500
10	39.5	7.7	0.16	0.01	56.3	0.02	0.00	0.00
11	36.0	7.4	0.30	0.13	12.0	0.03	0.01	0.00
12	45.0	7.8	158	0.02	25.6	0.02	0.00	0.00
13	41.0	7.3	0.47	0.09	10.6	0.02	0.00	0.00
14	47.0	7.0	0.38	0.04	3.32	0.03	0.00	0.00
15	52.0	7.3	0.61	0.04	20.5	0.02	0.00	0.00
16	41.0	8.0	0.83	0.05	27.4	0.03	0.00	0.00
17	36.0	7.8	0.31	0.01	11.6	0.01	0.00	0.00
18	40.0	7.7	0.31	0.01	10.10	0.02	0.00	0.00
19	38.0	8.3	0.28	0.17	7.74	0.03	0.00	0.00
20	30.5	7.7	0.10	0.01	7.4	0.02	0.00	0.00
21	30.0	7.8	.38	0.03	8.3	0.02	0.00	500
22	40.0	7.8	.10	0.00	0.0	0.01	0.00	500
23	46.0	7.5	0.09	0.01	8.3	0.03	0.01	0.00
24	29.5	7.6	0.1	0.01	14.1	0.12	0.01	0.00
25	45.5	7.6	010	0.01	8.2	0.01	0.00	0.00
26	40..0	8.0	0.10	0.01	14.1	0.04	0.00	0.00
27	50.0	8.5	010	0.01	5.2	0.01	0.00	0.00
28	52.5	7.2	0.52	0.02	4.1	0.01	0.00	0.00
29	50.0	8.6	0.10	0.01	14.1	0.01	0.00	0.00
30	56.0	8.7	0.4	0.03	7.1	0.01	0.00	0.00
31	54.0	8.1	0.19	0.00	11.5	0.02	0.00	500
32	49.5	8.4	0.09	0.01	8.3	0.02	0.00	0.00
33	50.0	8.7	0.12	0.01	0.0	0.03	0.01	500
34	50.5	8.3	0.12	0.02	11.8	0.02	0.00	0.0
35	46.5	8.9	0.12	0.01	6.2	0.03	0.01	500
36	47.5	7.6	0.51	0.16	32.2	0.02	0.00	0.0
37	41.0	7.8	0.34	0.02	6.3	0.03	0.01	500
38	43.0	7.7	1.84	0.02	1.2	0.03	0.01	500
39	45.0	7.7	0.36	0.01	2.0	0.01	0.00	0.00
40	50.0	7.7	0.47	0.64	135.4	0.02	0.00	0.00
41	50.0	7.9	0.61	0.01	1.2	0.02	0.00	0.00
42	40.0	7.6	0.36	0.01	2.0	0.02	0.00	0.00
43	47.5	7.9	0.33	0.03	8.6	0.02	0.00	0.00
44	47.5	7.6	0.28	0.03	10.1	0.02	0.00	0.00
45	42.5	7.7	0.58	0.01	1.2	0.02	0.00	0.00
46	39.5	7.7	0.37	0.01	3.8	0.03	0.00	0.00
47	39.5	7.8	0.74	0.02	2.9	0.04	0.00	0.00
48	38.0	7.5	0.64	0.01	2.2	0.03	0.00	0.00
49	38.0	8.3	0.20	0.00	0.00	0.03	0.00	0.00
50	43.5	7.8	1.10	0.14	12.9	0.03	0.01	300
Over all mean				.06	6.4		0.0013	104.0

*SP = saturation percentage, ECe = electrical conductivity, SAR = sodium adsorption respectively. The overall mean SD and CV value were 0.6 and 6.4, respectively.

The mean sodium adsorption ratio (SAR) ranged form 0.0 to 0.12%. Values of SD and CV of individual soil samples ranged from 0.0 to 0.01and from 0.00 to 500%, respectively. The overall mean SD and CV for all samples were 0.0013 and 104.0%, respectively. The calcium carbonate ($CaCO_3$) of the studied samples was shown in Table 4.3.

The mean calcium carbonate ($CaCo_3$) of the individual soil samples ranged from 0.00 to 7.8%. Values of SD and CV for the individual soil samples ranged from 0.00to 0.4% and 0.0 to 17.0%, respectively. The overall mean SD and CV for all samples were 0.1and 4.3% respectively.

The mean organic matter (OM) of the Surface soil samples ranged from 0.03 to 1.54%. Values of SD and CV for individual soil samples ranged from to 0.21% and from 0.0 to 125.7, respectively. The overall mean SD and CV for all samples were 0.03 to 4.82 respectively. The ratio of (Si + S)/C, C/(Si+S), (Si + S)/(C + $CaCo_3$), and (Si +S)/(C+OM) values for each samples were calculated and shown in Table 4.3.

4.2 Non-erodibile soil particles and wind erodibility:

The mean percentage of NEP (soil particles > 0.84 mm) of the studied samples was presented in Table 4.4. The mean percentage of NEP ranged from 15 to 66.9%. The SD and CV values for the individual soil samples ranged from 0.0 to 7.7.1% and from 0.0to 27.1%, respectively. The overall SD and CV of the sample were 1.3 and 3.6%, respectively. Values of the calculated wind erodibility index ranged from 34.2 to 262.0 (ton/ha). The overall mean wind erodibility of studied soil samples was 125.7 (ton/h).

Table 4.3 : Mean $CaCO_3$ and OM percentage, (Si +S)/C, C/(Si +S), (Si +S)/(C +$CaCO_3$) and (Si +S)/(C +OM) ratios of the studied samples*

No	$CaCO_3$	SD	CV	OM%	SD	CV	(Si+S)/C	C(SI+S)	(Si+S)/ (C+CO3)	(Si+S) /(C+OM
1	7.8	0.0	0.0	0.23	0.01	0.2	8.1	.1	4.7	4.9
2	7.0	0.3	4.0	0.50	0.01	2.8	8.1	.1	4.9	7.7
3	6.6	0.2	3.2.0	1.45	0.21	14.6	6.1	.2	4.2	5.6
4	0.0	0.0	0.0	0.53	0.0	0.0	4.6	.2	4.6	4.4
5	0.0	0.0	0.0	0.50	0.01	2.8	9	.1	9	8.6
6	6.0	0.0	0.0	143	0.03	2.0	5.3	.2	3.7	4.8
7	5.5	0.1	1..3	0.43	0.01	3.3	4.8	.2	3.7	7.7
8	6.2	0.4	6.8	0.79	0.04	5.4	4.3	.2	3.2	4.1
9	7.2	0.28	3.9	0.95	0.04	4.5	4.3	.2	3.1	4.1
10	6.8	0.0	0.0	0.45	0.01	3.1	4	.2	3.1	4.2
11	7.0	0.1	0.1	0.45	0.03	6.3	3.2	.3	2.6	3.3
12	4.5	0.0	0.0	0.75	0.07	9.4	3.3	.4	3.2	2.6
13	3.3	0.4	10.7	0.48	0.00	0.0	3.3	.3	3.4	3.9
14	3.1	0.1	2.3	1.11	0.06	5..5	2.7	.3	2.8	3.0
15	2.2	0.0	0.0	1.54	0.01	0..5	4.0	.4	2.2	2.2
16	3.5	0.5	14.1	0.36	0.03	7..9	32	.4	2.1	2.3
17	4.5	0.2	4.7	0.31	0.01	2..3	3.3	.3	3.3	3.9
18	4.0	0.0	0.0	0.87	0.07	8.1	3.3	.3	3.2	3.6
19	2.9	0.01	2.4	0.25	0.00	0.0	3.8	.3	3.5	4.0
20	6.6	0.1	2.1	0.19	0.00	0.0	3.8	.1	6.3	11.
21	4.4	0.2	4.8	0.20	0.00	0.0	4.0	.1	9	15.2
22	5.4	0.2	3..9	0.62	0.03	4..6	11.5	.2	3	3.7
23	2.1	0.1	6.7	1.52	0.00	0.0	15.7	.5	9.1	9.7
24	0.0	0.0	0.0	0.03	0.00	0.0	3.8	.1	49	48.3
25	0.0	0.0	0.0	0.35	0.01	2..3	11.5	.3	13.3	12.7
26	0.0	0.0	0.0	0.25	0.04	17.0	49	.3	6.4	8.8
27	1.8	0.2	11.8	0.45	0.00	0.0	13.3	.2	1.7	5.1
28	1.6	0.0	0.0	1.54	0.00	0.0	9	.2	7.4	1.9
29	1.1	0.1	12.9	0.38	0.08	22.3	5.3	.3	3	7.8
30	1.1	0.2	15.2	1.26	0.06	4..6	2	.3	3.9	3
31	5.6	0.0.0	0.0	0.45	0.04	9.4	8.1	.2	2.8	5.1
32	1.6	0.1	8.8	1.53	0.04	2.8	3.2	.3	4.3	2.1
33	0.0	0.0	0.0	0.44	0.00	0.0	5.3	.1	5.1	2.8
34	1.3	.1	10.9	1.11	0.00	0.0	3.	.3	5.2	3.7
35	0.0	0.0	0.0	0.47	0.04	9.0	4.3	.2	4.3	4.3
36	1.8	0.2	11.8	0.36	0.00	0.0	4.6	.2	5.1	5.5
37	2.8	0.28	10.0	0.44	0.00	0.0	5.7	.1	3.5	4.2
38	0.0	0.0	0.0	0.45	0.07	125.7	4.3	.2	3.3	5.5
39	.3	0.0	0.0	0.81	0.00	0.0	5.7	.3	4	3.2
40	0.0	0.0	0.0	0.51	0.00	0.0	4	.1	3.2	4.2
41	0.0	0.0	0.0	1.32	0.0	0.0	3.3	.3	8.8	3.1
42	.3	0.0	0.0	0.47	0.1	21.1	4.3	.2	3.1	8.6
43	.2	0.0	0.0	1.12	0.01	1.3	9	.2	5.2	3.3
44	2.2	0.3	12.9	0.48	0.03	5.9	3.3	.1	5.7	5.5
45	0.0	0.0	0.0	0.58	0.03	4.9	5.7	.2	10.1	5.5
46	0.0	0.0	0.0	0.21	0.01	6.7	5.7	.1	3.5	9.9
47	3.9	0.0	0.0	0.38	0.11	29.7	10.1	.2	8.1	4.2
48	3.3	0.0	0.0	0.36	0.00	0.0	11.5	.1	3.8	11.0
49	2.5	0.0	0.0	0.37	0.04	11.5	44.3	.2	2.3	4.2
50	2.5	0.4	17.	1.50	0.00	0.00	2.4	.4	2.3	2.3
Overall mean		0.1	4..3		.003	4.8				

*$CaCO_3$ =Calcium carbonate . O M =Organic matter Si =silt , S = sand ,C clay.

Table 4.4: Mean non – erodible particles (NEP) and wind erodibility of the studied soil samples

No.	NEP%	SD	CV	Erodiblity (ton/ha
1	21.4	5.8	27.1	209.2
2	44.9	2.1	4.7	108.2
3	58.6	1	0.5	48.8
4	47.7	.5	1.9	96
5	43.7	.9	6.5	109.6
6	54.	3.5	.4	65
7	33.5	0.1	1.3	152.5
8	50.1	.6	8.9	84.5
9	50.7	4.5	0.2	81.5
10	33.5	.1	0.0	152.5
11	33.4	0	1.7	153
12	52.9	.5	0.5	70
13	44.3	7.7	3.4	110.8
14	53.5	3.3	0.0	77.5
15	65.6	2.19	0.0	36.0
16	30.9	0	0.9	161.5
17	30.4	.3	3.8	164.0
18	50.9	.5	9.6	81.5
19	25.2	0.24	12.9	192.3
20	16.4	2.5	14.9	249.6
21	17.6	2.5	1.4	240.4
22	49.4	2.5	4.5	89.2
23	63.1	3.5	4.5	39.8
24	15	.1	10.4	262.0
25	33.5	.1	.4	152.5
26	25.3	.4	1.4	190.9
27	36.5	.2	.6	140.0
28	65.9	.4	.6	36.0
29	30.9	1.1	3.7	161.5
30	54.8	3.4	3.6	61.8
31	33.7	.4	1.1	151.5
32	65.6	1.1	1.7	36.0
33	33.6	.3	.8	152.0
34	51.3	1.5	2.9	78.5
35	34.1	0.07	.2	149.6
36	31.9	2.5	8.	160.2
37	33.8	0.14	.4	151.0
38	32.4	2.12	6.5	157.4
39	49.4	.99	7.9	89.2
40	43.9	1.7	3.9	112.8
41	66.1	1.8	2.8	35.8
42	35.7	.7	.2	142.5
43	63.8	.14	.2	38.4
44	36.2	1.8	4..9	140.6
45	46.3	2.5	5..5	103.8
46	19.1	1.3	.7	227.2
47	33.6	.3	.8	152.0
48	30.7	.8	3.	162.5
49	37.3	.71	3.6	137.5
50	66.9	.1	.2	34.2
Overall mean		1.3	3.6	125.7

The mean calcium carbonate ($CaCo_3$) of the individual soil samples ranged from 0.00 to 7.8%. Values of SD and CV for the individual soil samples ranged from 0.00 to 0.4% and 0.0 to 17.0%, respectively. The overall mean SD and CV for all samples were 0.1 and 4.3% respectively.

4.3 The relationship between NEP and soil properties:

The relationships between NEP and soil properties are computed using simple Regression analysis (Litter and Jackson, 1975) and reported in Table 4.5. Fig 4.1A shows highly significant power increase ($P< 0.001$, $R = 0.6515$) in NEP with increase in clay content. Clay content accounted for about 43% of the variability of NEP. The relationship between silt and NEP was not significant. Fig 4.1B shows significant exponential decrease ($P< 0.05$, $R =0.2821$) in NEP with increase in sand content. However, sand content accounted for about 8% of the variability of NEP. The relationship between $CaCO_3$ and NEP was no significant. Fig. 4.2A shows a highly significant ($P<0.001$ $R=0.9592$) quadratic increase in NEP with increase in OM, which accounted for about 96% of the variability of NEP. Fig. 4.2B shows highly significant power decrease ($P< 0.001$, $R=0.5791$) in NEP with increase in (Si+S)/C ratio. The plot also shows a highly significant ($P< 0.001$, $R = 0.5791$) decrease in NEP with increase in (Si + S)/C ratio. This ratio accounted about 31% of the variability NEP. Fig. 4.3A shows significant increase in NEP with increase in C/(Si + S) ratio ($P< 0.05$, $R = 0.3068$). Fig. 4.3B shows a highly significant decrease in NEP with increase in (Si+S)/(C+$CaCO_3$) ratio ($P< 0.001$, $R = 0.5819$). Fig. 4.3C shows a hilly significant decease in NEP with increase in (Si + S)/(C +OM) ratio.($P< 0.001$, $R=0.6798$).

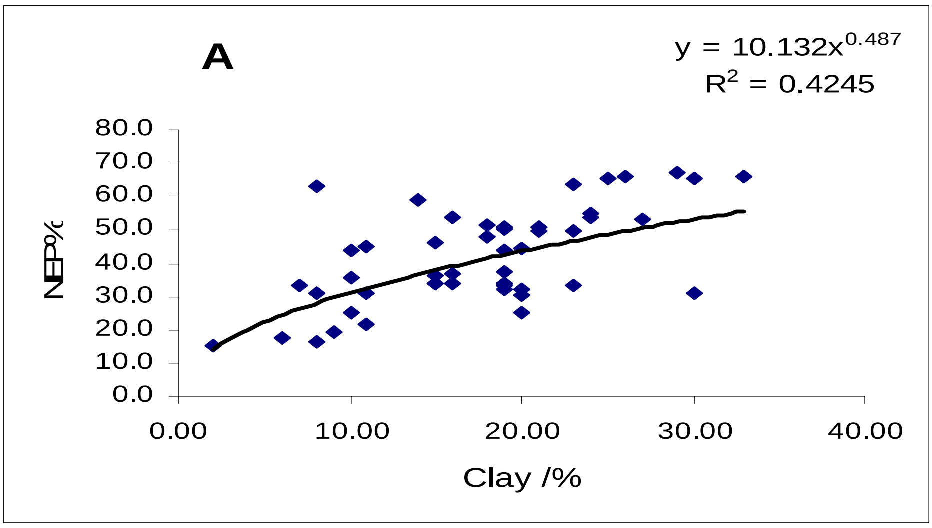
Table 4.5: Parameter for the equations of the trends lines showing the relationship between NEP % and soil properties*

Property	Type	a	b	C	R	R^2
Clay %	Power	10.13	0.49	_	0.6515	0.4245
Sand %	Expontional	64.92	0.08		0.2821	0.0796
OM %	Quadratic	-22.81	69.59	9.47	0.9592	0.9200
(Si+S)/C	Power	74.76	-0.39	-	0.5791	0.3353
C/(Si+S)	Power	77.98	0.42	-	0.6495	0.4218
(Si+S)/(C+$CaCO_3$)	Power	69.93	-0.39	-	0.5819	0.3386
(Si+S)/(C+OM)	Power	79.226	0.44	-	0.6798	0.4611

*$CaCO_3$, OM, Si, S and as explained in Table 4.3; NEP as explained in Table 4.4

Power: Y = a $x^{b;}$ Quadratic: Y= ax^2+bx=c; expontional: Y= ae^{bx}

R (0.05) = 0.2732; R (0.01) =0.3541, R(0.001) =0.4433.



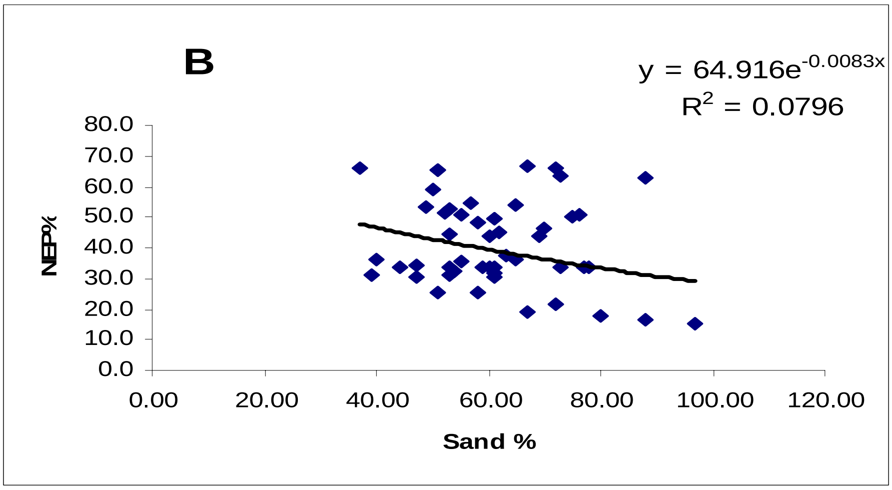
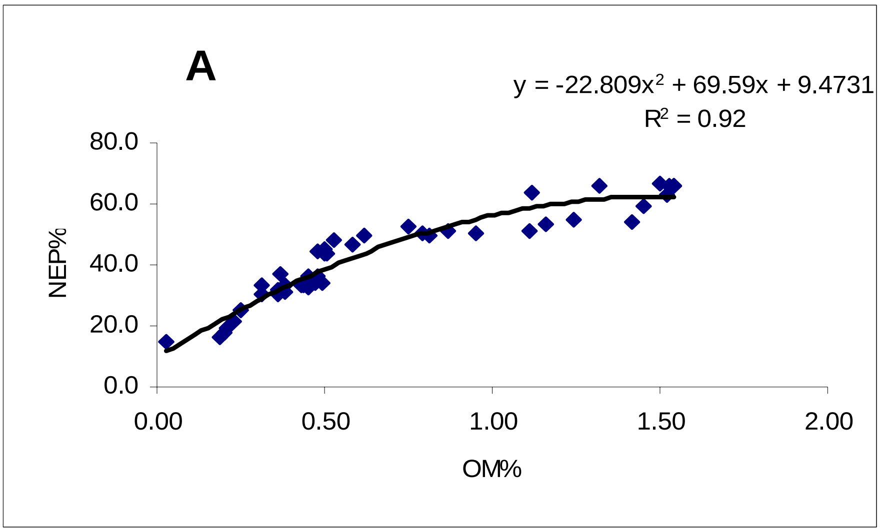


Fig 4.1. Non-erodibles particles (NEP) as a function of (A) clay content and (B) sand content



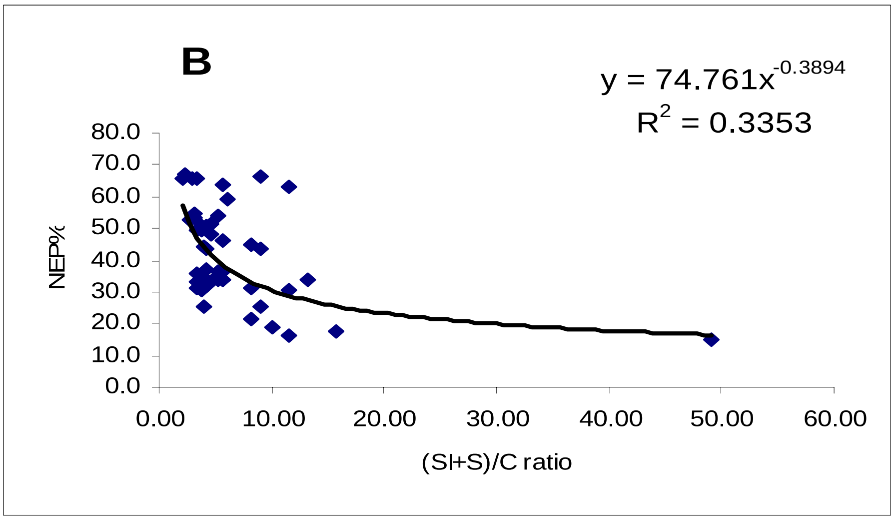
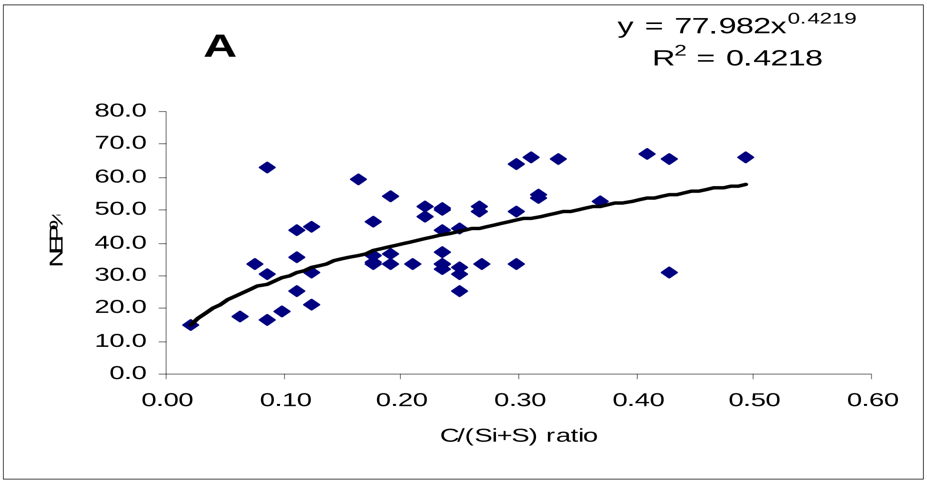
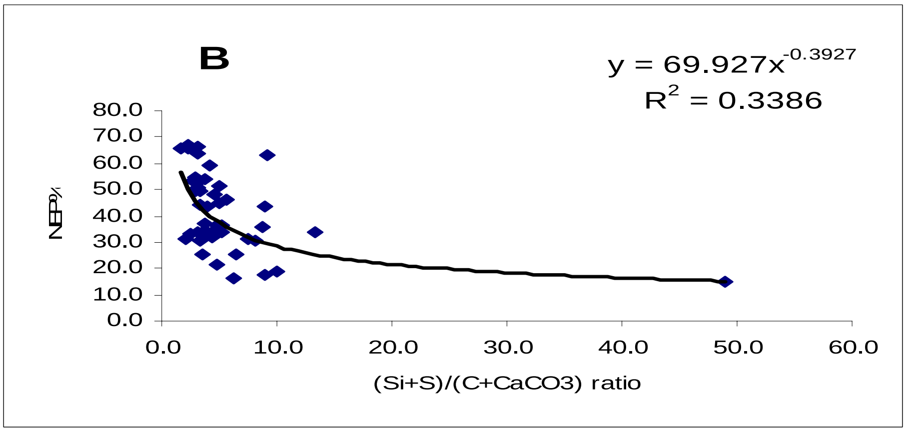


Fig.4.2 Non-erodible particles (NEP) as a function of (A) OM Content and (B) (Si+S)/C ratio





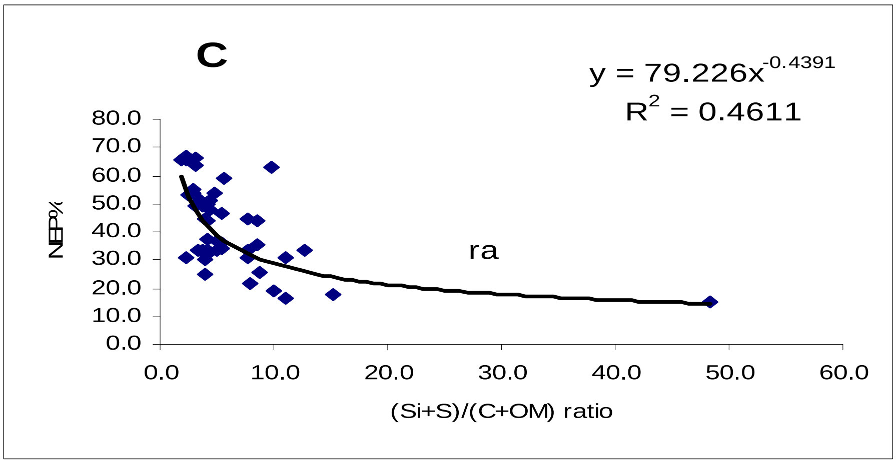


Fig. 4.3. Non erodible particles as a function of (A) C(Si+S), (B)(Si+S)/ (C+CaCo$_3$) and (Si+S)/(C+OM)

4.4 The relationship between wind edibility and soil properties:

Table 4.6 presents data of the regression lines showing the relationship between wind erodibility (WE) and soil properties. Fig 4.4A shows highly significant ($P< 0.001$, $R= 0.6273$) logarithmic decrease in wind erodibilty with increase in clay content. Clay content accounted for about 39% of the variability of WE. Silt content had no significant effect on WE. Fig 4.4 B illustrates significant Quadrate increase ($p<0.05$ $R=0.3248$) in WE with increase in sand content. However sand content accounted for about 11% of the variability of WE. $CaCO_3$ had no significant effect on WE. Fig 4.5 A shows a highly significant exponential decrease ($P<0.001$ $R =0.9563$) in WE with increase in organic matter content. Organic matter content accounted for about 91% of the Variability of WE. Fig 4.5B illustrates highly significant polynomial increase ($P< 0.001$, $R =0.3068$) in wind erodibilty with increase in (Si+S)/C ratio. This ratio accounted for about 31% of the variability of WE. The relationship between WE and C/(Si+S) ratio shows significant logarithmic decrease ($P< 0.001$, $R= 0.3068$) in WE with increase in C/(Si+S) ratio. This ratio accounted for about 9% of variability of WE .Fig 4.6A indicates highly significant logarithmic increase ($P< 0.001$, $R = 0.5651$) in WE with increase of (Si+S)/(C+$CaCO_3$) ratio. This ratio accounted for about 32% of the variability of WE. Fig 4.6B illustrates highly significant logarithmic increase ($P< 0.001$ $R =0.6603$) in WE with increase in (Si+S)/(C + OM) ratio. This ratio accounted for about 44% of the variability of WE.

The correlations between WE and both ECe and SAR were no significant.

Table 4.6 Parameter for the equations of the trend lines showing the relationship between wind erodibility (WE, ton/ha) and some soil properties

Property	Type	a	b	c	R	R2
Clay%	Logarithmic	-73.92	328.29	-	0.62729	0.3935
Sand%	Quadratic:	0.06	-5.97	273.52	0.3248	0.1055
O.M%	Exponential	249.17	-1.25	-	0.9563	0.9146
(Si+S)/C	Quadratic	714.57	491.84	11.73	0.3068	0.5172
C/(Si+S)	Logarithmic	0.00	-0.17	190.01	0.3068	0.0941
(Si+S)/(C+CO_3)	Logarithmic	60.16	34.26	-	0.5651	0.3193
(Si+S)/(C+OM)	Logarithmic	67.32	15.06	-	0.6637	0.4361

* $CaCO_3$, O M, Si, S, and C as explained in Table 4.3

Logarithmic: $Y = a\,Ln(x) + b$, Quadratic: $Y = ax^2 + bx + c$ exponential $Y = a\,e^{bx}$

R (0.05) =0.2732; R (0.01) = 0.3541, R (0.001) =0.4433

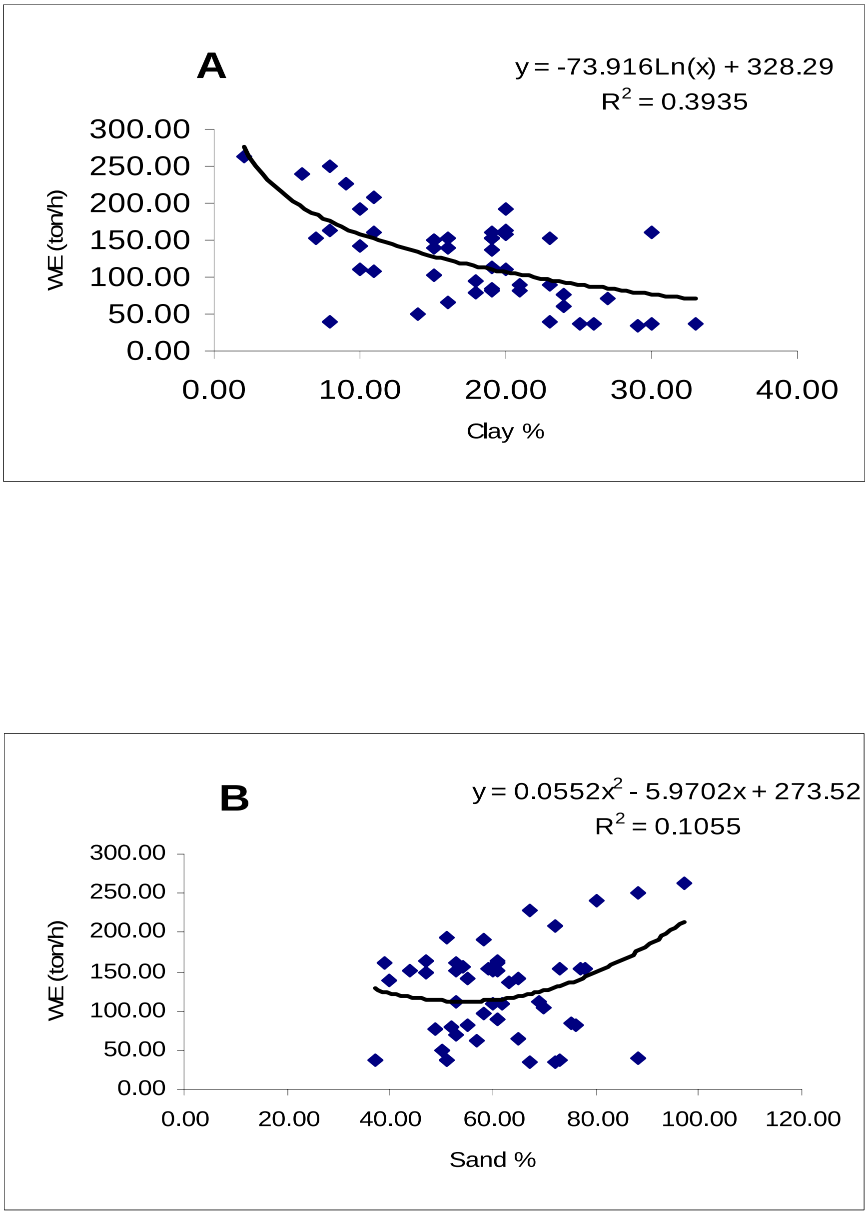
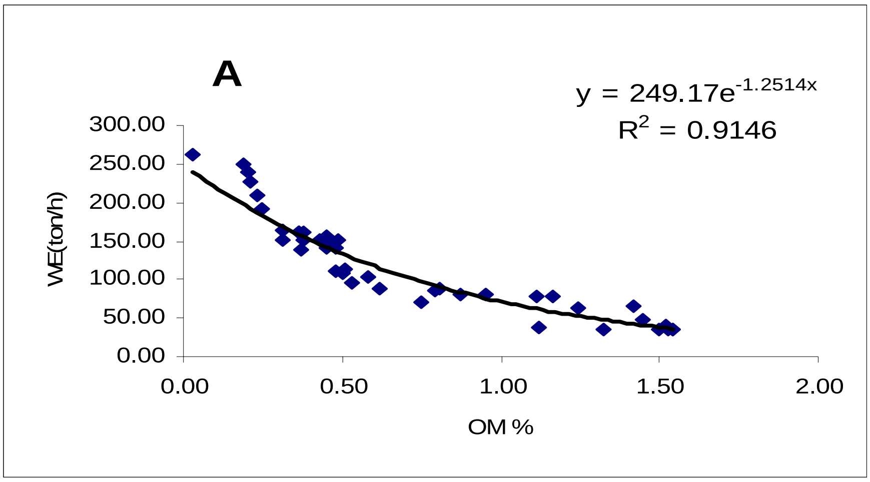


Fig.4.4 Wind erodiblity as a function of (A) clay content and (B) sand content.



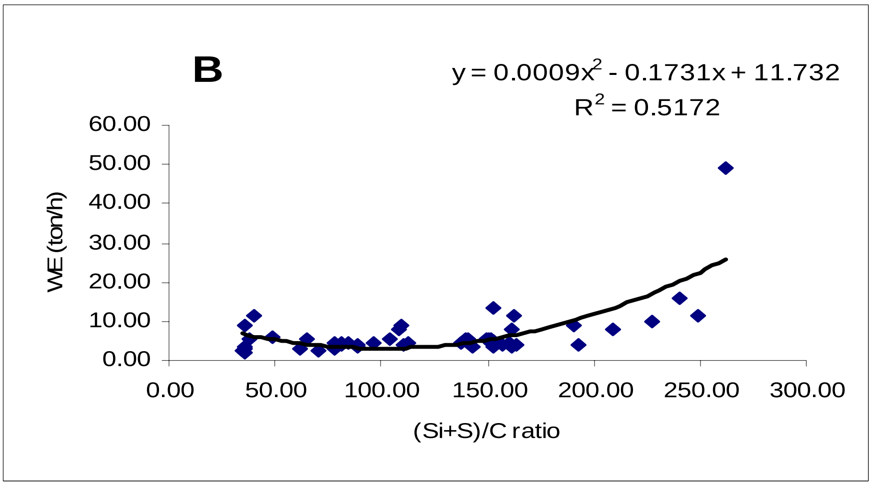


Fig. 4.5. Wend erodibility as a function of (A) O.M content and (B) (Si+S)/C ratio.

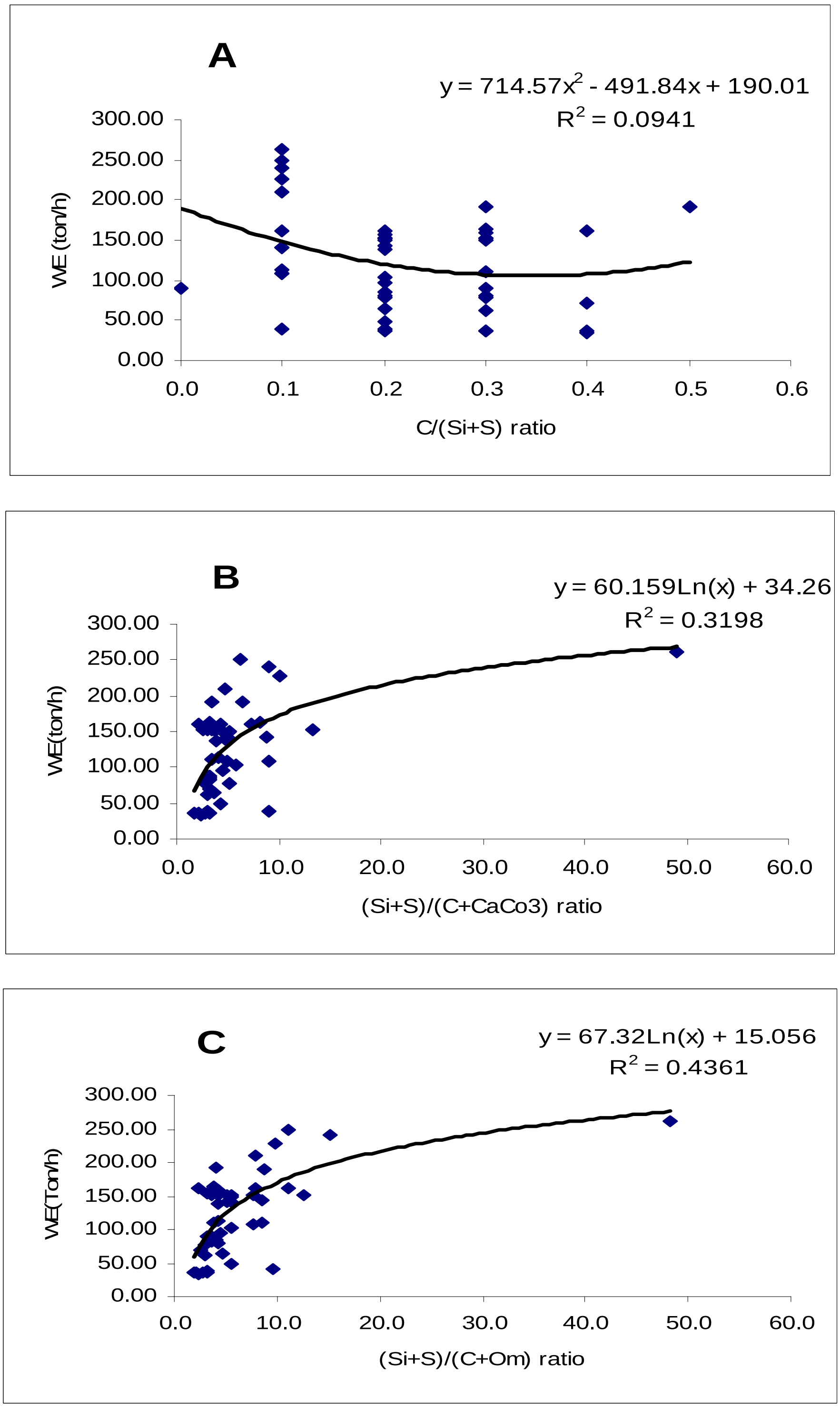


Fig. 4.6. Wind erodibility as a function of (A) C/(Si+S) ratio (B) (Si+S)/(C+CaCo3) ratio and(C) Si+S)/C+OM) ratio.

4.5 Wind erodibility groups (WE GS):

The studied soil samples were grouped into wind erodibility groups (WEGs). The mean percentages of non-erodible soil particles were calculated for each WEG and compared with those estimated from the WEGs obtained for N.Dakota (Chepil, 1962; Chepil *et al*., 1962., Hayes, 1955) and Alberta (Black and Chansyk, 1989). Table 4.7 shows the data.

Statistical analysis showed a highly significant correlation between the WEGs of Kassala State soil samples and those WEGs obtained from North Dakota (P< 0.001, R= .0 6339) and significant correlation from WEGs of Alberta (P<0.001 R= 0.5255).

4.6 Mapping of wind erodibility and relevant indicators:

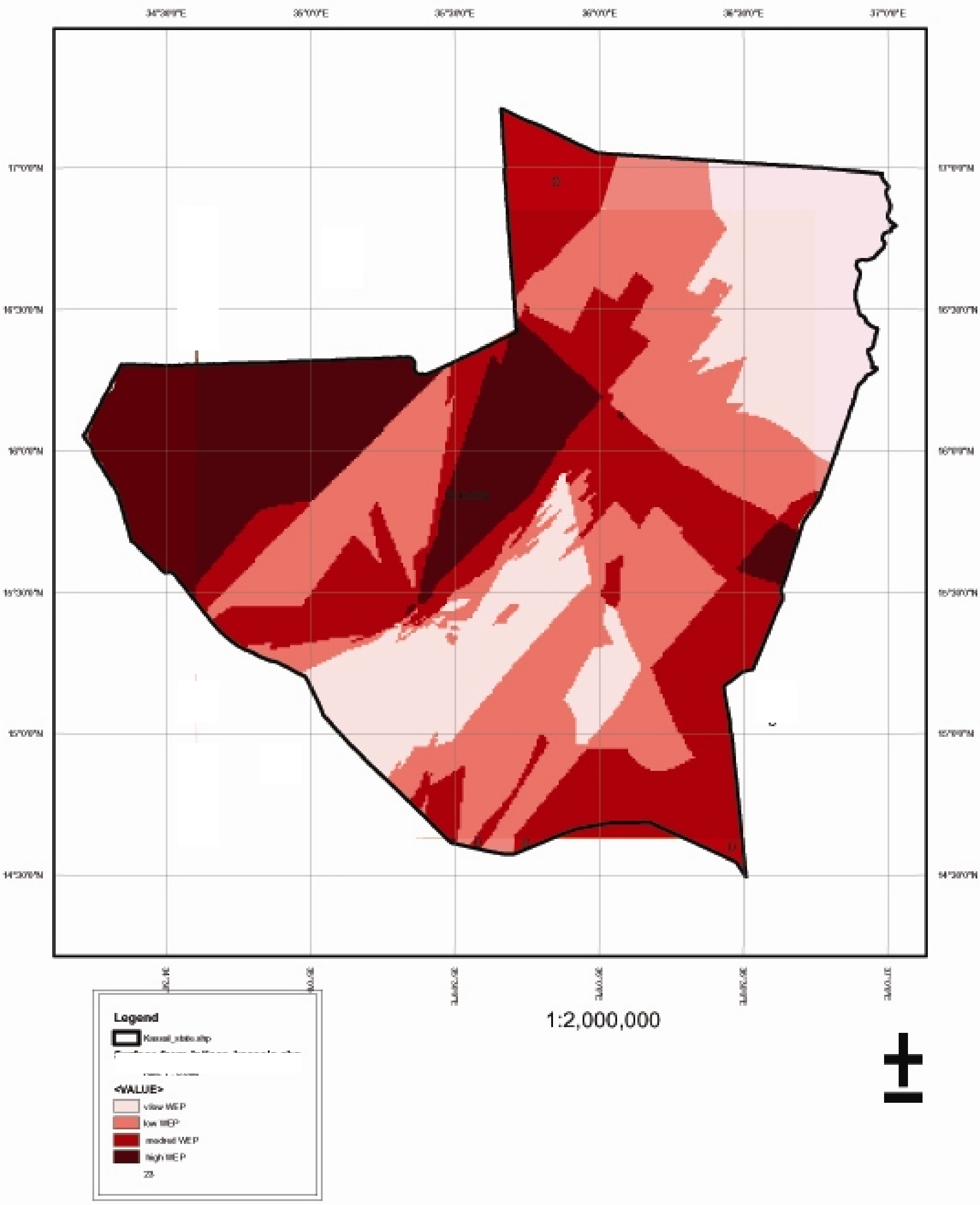
Map 4.1 shows the distribution of wind erodibility in the Kassala State. WE was classified into four classes, according to the average of erodibility values for each texture class, and then the range between minimum and maximum values for each erodibility class was made.class1 (very low erodibility) ranged from 35.2 (ton/h) to 48.8 ton/ha. This class was found in north-eastern Kassala State and small part binges from center and ends into south-western the state. Class 2 (low erodibility) ranged from 48.8 (ton/h) to 96.0 ton/ha. It dominates class on the most of state. Class 3 (moderate erodibility) ranged from 96.0 (ton/h) to 209 (ton/h). Class4 (high erodibility) ranged from 209.2 (ton/h) to 262.0 ton/ha. This class was found in west part of the state.

Table 4.7: The mean percentage of measured non –erodibile soil particles (NEP) for the various wind erodibility groups (WEG) compared with equivalent values obtained from the WEG of North Dakota and Alberta

WEG	No. of sample	NEP		
		Measured	N.Dakota	Alberta
Clay	-	-	25	60.8
Sandy clay	1	25.2	45	57.9
Sandy clay loam	19	48	40	-
Sandy loam	20	39.2	40	56.2
Loamy sand	3	22.5	3.0	21.5
Sand	1	15	-	6.0
Silt loam	1	30.9	-	-
Clay loam	1	65.9	45	57.9
Silt	1	37.3		
Loam	3	43.0	45	57.9
Correlation coefficient(r)*			0.5255	0.6339

*r 0.001 =0.5013

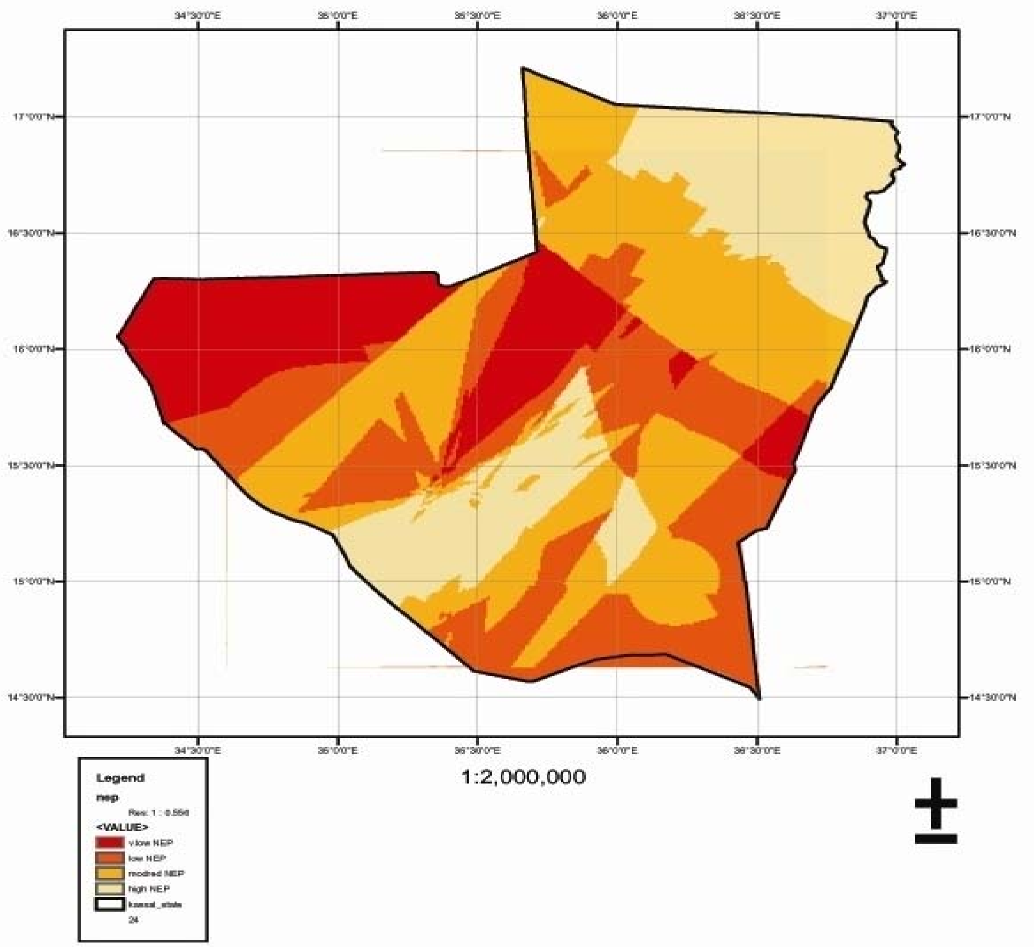
Map 4-1 : Assessment Of Wind Erodibility In Kassala State



Most of the state is located under the low class of the erodibility. The benefits of using GIS techniques to illustrate the erodibility add more generalization to the area.

Map 4.2 illustrates the distribution of NEP on the Kassala State. NEP were divided in to four classes according to the average for each texture class kike what happen above in wind erodibility classification. Class 1 (very low NEP) ranged from 15 to 30.9%. This class was found where the high erodibility class was found. Class 2 (low NEP) ranged from 30.9 to 39.9%. It is dominate in most of the lands of the state. Class 3 (moderate NEP) ranged from 39.9 to 48.0%. This class was found where the low erodibility class was found. Class 4 (high NEP) ranged from 48.0 to 65.9%. This class was found where the very low erodibility class was found.

Map 4-2 : Assessment of Non. Erodible Partiicles in Kassala State



CHAPTER FIVE
DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussions:

The rate at which wind erosion occurs depends on three main factors soil erodibility, soil erosivity and roughness of surface (Mustafa, 2007). Soil erodibility is mainly dependent on the stability of the soil particles more than 0.84 mm in diameter, which are, considered non-erodibile (Chepil, 1955). The results obtained from the studied samples showed positive correlation between NEP% with clay and organic matter (OM) contents. Clay and OM accounted for 42 and 92 of the variability of NEP, respectively. Clay fraction and derivatives of organic matter acted as cementing agents, and hence promoted soil aggregation and increased the relative proportion of NEP. The positive correlation between NEP % and clay and OM agreed with all previous studies (Mustafa and Medani, 2003; Rehan, 2004; Abdelwahab, 2005 and Hassan, 2006). In contrast sand contents gave negative correlation with NEP. This result agreed with previous findings (Mustafa and Madani, 2003; Rehan, 2004, and Hassan, 2006). However, the accountability of sand for NEP variability was very low. Sand particles can not form aggregates in absents of cementing agents because they are essentially inert quartz particles.

Silt did not give significant correlation with NEP. Morgan (1995) noted that silt particles are the least resistance to wind erosion and soils with high silt content are the most erodibile, moreover soils with 40 - 60%

silt content are most erodibile (Richter and Negendonk, 1979). It was found that NEP increases as C/(Si + S) ratio increases and decreases with increases in clay ratio (Si + S)/C. These ratios gave significant correlation with NEP with accountability of about 42 and 33%, respectively. The ratio of (Si+S)/ (C+$CaCO_3$) showed highly significant negative correlation with NEP and accounted for about 34% of the variability of NEP. This result agreed with previous findings (Mustafa and Medina, 2003; Rehan, 2004; Mohamed, 2004; Abdelwahab, 2005; Hassan, 2006; Mohamed, 2006). The (Si +S)/(C + OM) ratio showed highly significant correlation with NEP and accounted for about 46% of the variability of NEP. This ratio gave highest correlation with NEP. This result agreed with previous findings (Medani and Mastafa, 2003 Rehan, 2004; Mohamed, 2004; Abdelwahab, 2055; Hassian, 2006).

Soil parameters gave significant correlation with the WE. The effect of clay, sand and O M contents on WE were the reverse of their influence on non-erodibile particles (NEP). Accountability of clay, sand, O.M, C/(Si+S) C/(Si + S), (Si + S)/(C + O.M), (Si+S)/(C+$CaCO_3$) for WE was slightly lower than for non-erodibile Particles.

The data showed that most of the studied samples were susceptible to erosion due to the restricted clay content. The mean clay contents of the studied samples ranged from 11 to 30%. Evans (1980) stated that soil with restricted clay fraction 9 - 30 percent were the most susceptible to erosion.

The results showed that mean of non-erodibile particles percentage range from 15.0 to 66.9%. The over all mean of soil erodibility was

125.7 ton/ha. The higher WE value of studied soil samples may be attributed to the predominate sand texture of the soil samples of the state which enhance the formation of aggregates, decreased NEP and increase WE.

The results showed that the studied samples were non saline (ECe >4sd/m) non sodic (SAR >15%), that may be due to the annul river Gash dispose.

The studied samples were grouped in to WEGs and then correlated with those of North Dakota and Alberta. Significant positive correlation was found between the WEGs of studies and the WEGs of those of N. Dakota (R= 0. 639) and Alberta (R =0.5255).

5.2 Conclusion:

The study was conducted to assess and map wind erodibility of the state. Wind erodibility of Kassala State soils is low.

The study illustrated significant correlation between non-erodibile Particles percentage or wind erodibility with some physical and chemical soil properties namely, clay, sand, OM, contents.

Multiple regression analysis yielded highly significant correlation between the five basic soil properties and NEP (R= 0.9400) or WE (R= 0.9174).

Grouping of soils into WEGs for the Kassala State textured soils gave significant with other WEGs studied in Alberta and North Dakota soils.

5.3 Recommendations:

- The study area in Kassala State gave indicators of NEP % and WE.
- The results yielded that (Si +S)/(C+OM) ratio is the best indicator of WE, so, the following equation is recommended for predicting NEP of Kassala State.

$$NEP (\%) = \{79.226(Si + S)/(C+OM)\}^{-0.4391}$$

$$(R^2 = 0.4611,\ n = 50)$$

- It is recommended to predict NEP using the above empirical equation and look up WE from the standard table.
- The result yielded significant correlation between clay, sand, organic matter, and organic matter gave highest accountability of the variability for both NEP and WE. Thus OM is recommended as a single indicator of NEP, and the following equation is recommended for predicting:

$$NEP = -22.809(OM)\ 2 + 69.59(OM) + 9.471$$

$$(R^2 = 0.92,\ n = 50)$$

REFERENCES

Abdelwahab, M.H. (2005).Wind erodibility of soil from Northern State. M.Sc. Thesis (desertification), U of K.

Ayoub, A.T. (1998). Extent, severity and causative factor of land degradation in the Sudan. Journal of Arid Environments 38: 397-409.

Black, C.A.; Evans D.D; Ensminger, I.C and Clark, F.E. (1965). Methods of Soil Analysis (part 1) Agronomy. Monograph No. 9, American Society of Agronmy, Inc., Madison, Wisconsin, USA.

Black, J.M. and Chansyk, D.S. (1989). The wind erodibility of some Alberta Soils after Seedling. Aggregation in relation to field parameter. Canadian Journal of Soil Science, 69: 855-874.

Borohona, E., J. Quirantes, J.L Guardiola and Airiate (1990). Factors affecting the susceptipibility of soils to interrill erosion. In south eastern Spuain. In J L Rubio and R J Rickson (eds) Strategies to combat desertification in Mediterranean Europe Commission of European committed Report EUR 11175 ENIES: 46-47.

Chapman, H.D. and Pratt, P.F. (1961).Methods of Analysis of Soil, Plants and Water. University of California, Division of Agricultural. Science, USA.

Cheng, K.L., and Bray, R.H. (1951). Determination of calcium and magnesium in soil and plant material. Soil Sci.72: 449-458.

Chepil, W.S. and R.A. Miline (1941).Wind erosion of soils in relation to size and nature of exposed area. Scientific Agriculture 21: 479-755, 759.

Chepil, W.S. (1950). Properties of soil which affluence wind erosion: II. Dry aggregate structure as an index of erodibility. Soil Science 96: 403- 414.

Chepil, W.S. (1955). Factors that influence clod structure and erodibility of soil by wind. IV sand, silt and clay. Soil Science, 80: 155-162.

Chepil, W.S. and Woodruff, N.P. (1963). The physical of wind erosion and its control. Advances Agronomy 15: 211-302.

Clafin, L.E.; Stuteville, D.L. and Armbrust, D.V. (1973). Windblown soil in the epidemiology of bacterial leaf spot of alfalfa and common blight of beans. Physiopathology 36: 1417-1419.

Ekwue, E.L JO ohu, I H Wakawa (1993). Effect of incorporating two organic matter martial at varying level on splash detach of some soils from Boron state, Nigeria Earth structure process and land forms 18: 399-406.

Elwell, I.L.; H.A.; M.A., Stocking (1976).Vegetal cover to estimate soil erosion hazard in Rhodesia. Geoderma 15: 61-70.

ESA (European space Agency) (1998). ESA home page http://www. ESA activities in Global positioning system (GPS) what is GIS?

ESRI (Environmental System Research institute) (1993). Learning GIS, The ARC/Info method red lands, CA: ESRI.

ESRI (Environmental System Research Institute) (2007**).** Home Page http://ESRI@ yahoo.com.

Evens, R. (1980**).** Mechanics of water erosion and their spatial and temporal controls: an empirical view point. In M.J. Kirby and R.P.C.

Food and Agriculture Organization Untied Nation (1960**).** Soil erosion by wind and measure for its control on agricultural lands Development paper No. 71, FAO.

Food and Agriculture Organization Untied Nation (1977). Assessing of Soil Degradation FAO. Soil Bulletin No. 13, FAO.

Hamid, K.S. and Mustafa, M.A. (1975). Dispersion as an index of relative hydraulic conductivity in salt-affected soils of the Sudan Geoderma 14:107-114.

Harahsheh, Hussein, and Tateishi, Ryutaro (2000). Environmental GIS database for desertification studies in West Asia Global change; desertification mapping of West Asia. A GIS and remote Sensing application. www.gis development.net/aars.

Hayes, W.A. (1965). Wind erosion equation useful in designing north eastern crop protection. Journal of Soil and Water Conservation 20: 153-155.

Hayes, W.A. (1966). Guide for wind erosion control in the Northeastern State, Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C.

Hussein S.G. (2006). Afforaestation in Arid lands with particular reference to the Sudan sited – Khartoum. Khartoum University Press.

Litte, T.M., and Jackson. (1975). Statistical methods in Agricultural Research. UCD Book stores. Unit of California. Davis 95616.

Medani, G.H and Mustafa M.A. (2003).Wind erodibility of Soils from North Darfur State. U. of K. J. of Agric. Sci. 11: 369- 384.

Mohammed, Alawia. Y. (2004) .Wind erodibility of Soils from White Nile State M.Sc. Thesis Desertification U of K.

Morgan (eds), Soil Erosion.Chichester, John Wiley and Sons, pp 109-128.

Morgan, R.P.C. (1995). Soil Erosion and Conservation.2nd Edition, Longman Group Ltd., U k. Essex, Englandm pp. 198.

Mustafa, M.A. and Median, G.H. (2003). Wind erodibility of soil from Khartoum State, U. of K. J. of Agric. Sci. 11: 149-164.

Mustafa, M.A. (2007). Desertification processes. Unisco Chair of Desertification, University of Khartoum.

Rechards, L.A.; lesson, L.E.; Ernstein, L. Bower; C.A.; Brown, L.W. Fireman .M; Hatcher, J.T.; Hayward, H.E., Pearson, G.A. Reeve, R.C. wilox, L.A. (1969). Soil and Water Conservation Research Branch Agriculture Handbook No. 60.

Rehan, S.A. (2004). Wind erodibility of The Gezira state M.Sc. Thesis Desertification U of K.

Richter, G. and Negendank, J.F.W. (1977). Soil erosion process and Their Measure in the German area of Moselle River. Earth Surface Processes 2: 261-278.

Rions, Modame, M. H., Aggarwal, S.P. and Silva Ranjith Premalal De (2007). Application of remote sensing and GIS on Soil erosion assessment at Bata river basin, India. www.gis. Development net /application/ geology/geomorphology/geogfoo1.htm.

Sangan, C., Owen, B.T. and Pollack J.B. (1979). Anthropogenic albedo Changes and the earth's climate. Science 206:1363-1368.

Shainberg, I, and J. Letey (1984). Response of soils to sodic and saline condition Hilgradia 52: 1-57.

Skidmore, E.L and Woodruff, N.P. (1968). Wind erosion forces in the Untied States and their use in predicting soil loss. USDA Handbook No. 346, 42 pp, Washington DC.

Skidmore, E.L. (1979). Wind erosion. In: "The Encyclopedia of Soil Science part 1." Edited by R.W. Fairbridge and C.W. Fink 1, Jnr. P, Dowelen Hutchinson and Ross, Inc., Stroudsburg, Pennsylvania, U.S.A.

Slatting, J.H. (1957). Soil Conservation Engle – Wood cliffs N.J Premtice Hal.

Toon, Owen. B.D. and Pollack J.B. (1980). Atmospheric Aerosols and climate. America Scientist 68:268-278.

UNCCD (United Nation Convention to Combat Desertification) 1994.

Vorney, R.P., Van Veen, J.A. and Paul, E.A. (1981**).** Organic carbon dynamics in grassland soils. II model validation and simulation of the long-term effects of cultivation and rainfall erosion. Canadian Journal of Soil Sci. 61: 211-214.

Walkey, A. (1935). An examination of methods for determinate organic carbon and nitrogen in soils. Jour. Agr. Sci. (England) 25: 598-609, illus.

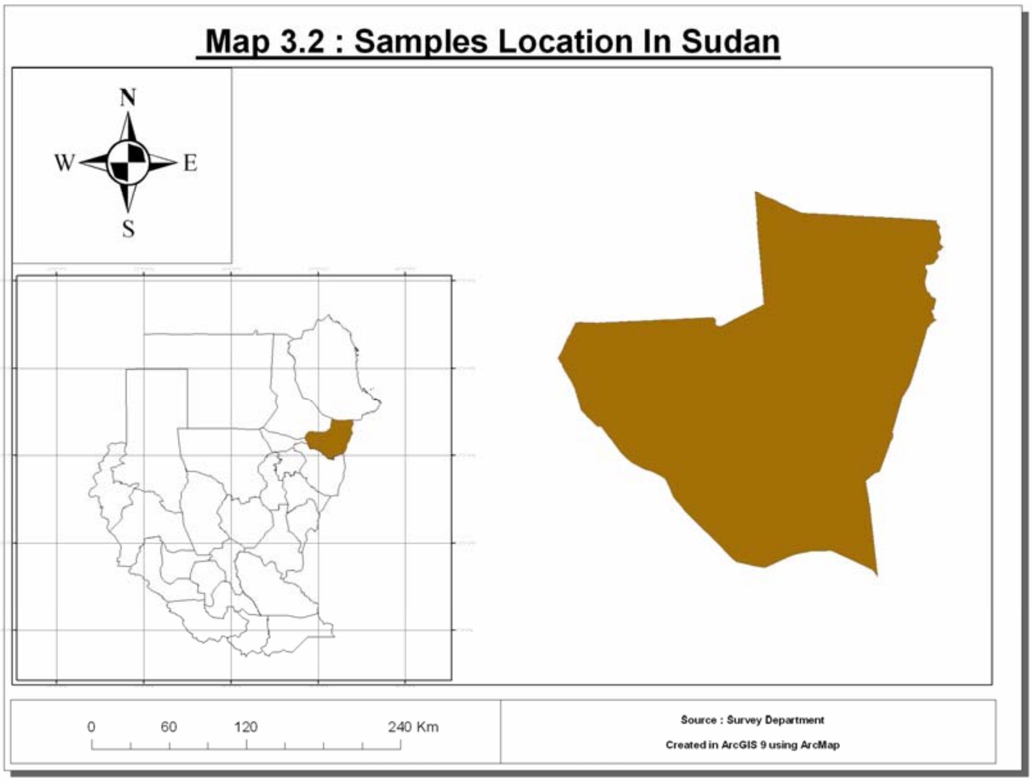
Woodruff, N.P., W.S. Chepil, and R.D. Lynch. (1957**).** Emergency chiseling to control wind erosion. Technical Bulletin 90. Kansas Agriculture Experiment Station, Manhattan.

Woodruff, N.P. and F.H. Siddoway, (1965**).** A wind erosion equation. Soil Science Society of America proceeding 29: 602 – 608.

Woodruff, N.P., L.Lyles, F.H. Siddoway and D.W. Fryrear. (1992). How to Control Wind erosion. Agriculture Information Bulletin No. 354. Agriculture Research Service, U.S. Department of Agriculture, Washington, D.C., 22 pp.

Younis, Mohamed, Gamal, Ahmed and Abdulla**,** Tag Elsir, Basheer. (1987). Artificial catchments to provide water for nomads Eastern region (report). Soil Conservation, Land Use @Water Programming Administrations in Association with UNDP Khartoum. Sudan.

APPENDIX


Map 3.2 : Samples Location In Sudan
N
W
E
S
0
60
120
240 Km
Source : Survey Department
Created in ArcGIS 9 using ArcMap